DRAFT

DEVELOPMENT OF ULTRAHIGH-STRENGTH READY-MIX SEMILIGHTWEIGHT CONCRETE

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120 pp

MAY 13 1985

MICROMEDIA

Contract No. : 1SQ83-00206
Requisition No.: 23440-3-9201
Financial Code : 214-131-000000-425252-0421
Levelton File : 83-770C

November 15, 1984

ACKNOWLEDGEMENTS

The authors wish to thank Dr. Mohan Malhotra, P.Eng., and Mr. Harold Wilson, P.Eng., of CANMET for their contributions to the methodology, materials selection process, and overall direction of these investigations.

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SYNOPSIS

Semilightweight portland cement ready-mix concrete has been available in ranges between 30 and 40 MPa for many years.

Prompting by Arctic Island construction demands, an expanded technology utilizing concrete pumping techniques, high-range water-reducing admixtures (superplasticizers), and flowing concrete has raised reasonable design expectations to compressive strengths greater than 45 MPa and dry unit masses on the order of 1,900 kg/m^3.

Background data assembly on new methods and materials available for ready-mix concrete was previously presented in the authors' March 1984 report, "Development of Ultrahigh-Strength Concrete, Phase I, Background Data Assembly". It was concluded therein that 70 MPa compressive strength semilightweight concrete was achievable in the Canadian marketplace.

Presented here are results of 162 trial mixtures using three coarse aggregate sources, two chemical admixture systems, three levels of fly ash replacement, and three levels of silica fume replacement.

It is concluded in these investigations that target 70 MPa concrete is attainable in semilightweight, that benefication by Type F ash replacement occurs, that silica fume contributes significantly to higher strengths at a late acceptance age, and that retarded early-strength gain of extended-window superplasticizers poses a potential impediment to early strength.

Increases in cementitious mass in the range tested, 450 to 550 kg/m^3, show no significant strength improvement.

Dispersion of pozzolanic substitutions, particularly silica fume, is addressed.

Canadian raw materials have been exlusively used in the program, as have been Canadian Standards Association qualification tests.

I. INTRODUCTION

CANMET, Mineral Science Laboratories under DSS File No. 15SQ.23440-3-9201, Contract Serial No. 1SQ83-0026, has commissioned B.H. Levelton & Associates Ltd. to carry out an engineering development of ultrahigh-strength, semilightweight concrete.

This program has been segmentalized into three phases. Phase I, Background Data Assembly, has been reported dated March 26, 1984.

After a review of property demands and process feasibilities established in Phase I, trial mixing and subsequent strength testing have now been completed for 162 mixture designs. This report conveys results and conclusions, along with recommendations for Phase III, which will address the specialized concrete parameters needed for high-performance service, such as in Arctic offshore structures.

The technology of proportioning, mixing, and testing have been held as closely as practicable within the conventions of transit mix (ready-mix) concrete production. Efforts have also been made to make the processes reproducible within existing field construction capabilities.

II. BASIS OF THE PROGRAM

The optimization from 162 trial mixtures of materials and methods for Phase II has striven to achieve the following targets:

1. Compressive strength 70 MPa (at 91 days);
2. Shear strength 5 MPa at like maturity (tested in this program as splitting tensile);
3. A minimum flowable consistency at maximum superplasticizer dosage and corresponding minimum water : cementitious ratio.

Phase III will address refinements of necessary supplementary properties, including:

1. Air entrainment for freeze/thaw durability;
2. Decreased permeability;
3. Maximization of impact and abrasion resistance;
4. Volume stability approaching normal mass concrete;
5. Air-dry density less than 1,900 kg/m^3.

One source of cement, fly ash, and silica fume was employed. Two sources of lightweight, coarse aggregate and one reference normal-weight aggregate were evaluated.

Two systems of chemical admixtures were tested (each system integrating low-range and high-range [superplasticizing] water reducers and neutralized vinsol resin air-entraining agents).

Variables in the trials included:

1. Three levels of fly ash replacement - 0, 12.5, and 25% by mass of cementitious;
2. Three levels of silica fume - 0, 7.5, and 15% by mass of cementitious;
3. Three levels of gross cementitious content - 450, 500, and 550 kg/m^3.

III. CONSTITUENT MATERIALS

A. General Selection

The authors, in their Phase I Report, outlined several selection demands drawn from the review of literature. These are summarized as follows:

1. Type 20 portland cement throughout;
2. Type C or consistent Type F low-carbon fly ash;
3. Neutralized vinsol resin as air-entraining agent;
4. High-range water-reducing admixture, extended-window type;
5. Nonchloride-ion type conventional water reducer (low range);
6. Standard-mass concrete sand with a fineness modulus between 2.8 and 3.0;
7. Lightweight expanded-clay shale optimal strength performers from two Canadian sources 14 mm maximum-size aggregate;
8. Silica fume from a Canadian source as closely matched to Nordic recommended chemical contents as possible.

B. Portland Cement

The authors reviewed Mill Certificates for eight Canadian product cements conforming to the requirements for Type 20 under CSA CAN 3.A23.5-M82. A short list of two included Genstar Cement Tilbury source Type 20 and Canada Lafarge Richmond source Type 20, both of which are used in ready mix in British Columbia.

Drawing upon B.H. Levelton & Associates Ltd. files, the performance of both in ready-mix concrete where more than 400 kg per cubic metre of portland concrete were employed was reviewed. The determined strength-efficiency advantages of Canada Lafarge was 12%. The tricalcium-silicate to tricalciumaluminate ratio reinforced its selection, based on smaller hydration-product performance in high-strength concrete.

Salient physical and chemical properties for the product used in trial mixtures were as shown in Table A.

TABLE A

CANADA LAFARGE TYPE 20 CEMENT

APRIL 1984

IDENTIFICATION	TEST RESULTS	CSA A5 LIMITS
Setting Time	150 minutes	360 maximum
Fineness 45 um	93.1%	72 minimum
Autoclave	+0.15%	1.0 maximum
Compressive Strengths		
3-Day (MPa)	20.7	10.0 minimum
7-Day (MPa)	30.2	16.0 minimum
Blaine Fineness (cm^2/gm)	3,850	--
Silicon Dioxide	21.2	--
Al_2O_3	4.3	--
Fe_2O_3	3.2	--
Calcium Oxide Total	64.0	--
MgO	1.4	5.0 maximum
Sulphur Trioxide	3.0	3.0 maximum
Loss on Ignition	1.0	3.0 maximum
Insoluble Residue	0.6	0.7 maximum
Total Alkalies	0.6	--
Tricalcium Aluminate	6.0	7.5 maximum
Dicalcium Silicate	20.1	--
Tricalcium Silicate	54.0	--
Tetra Calcium Ferro Aluminate	9.9	--

C. Fly Ash

Low-carbon fly ash was sought to meet the demands of the trial mix program. Several fly ashes from Alberta, Saskatchewan, and Washington State were considered. The short list of two products included Centralia Washington Type F and Sundance Alberta (classified ash). The fineness uniformity of other products was primarily responsible for their elimination.

The Blaine fineness of Sundance is 500 cm^2/gm higher than the Centralia source. Lower sulphate and higher calcium-oxide contents reinforced the selection of Sundance classified. Some salient laboratory properties and comparison with CSA A23.5 Standards are presented in Table B.

D. Silica Fume

Three sources of North America silica fume were considered. Owing to the extreme fineness of all, the relative reactivity predicated upon fineness was largely discounted in the selection process. As indicated in the prior report, a product most closely matched to the Nordic experience chemical thresholds was sought. The Norsep limits are cited in Table C along with test values for SKW fume.

The sources considered are ADI, Hannah, and SKW (Montreal). ADI presents silica at less than 84% and carbon greater than 4% while maintaining silica in excess of 92%. Hannah source material has carbon contents as high as 10%. SKW source material was, therefore, selected for all trials.

A physical assessment of the particles distribution was undertaken using an electron scanning microscope. Results of that survey demonstrate well-graded particles between 100 and 4,600 angstroms. Fifty percent of the material is estimated to be finer than 700 angstroms. Figure 1 shows a scaled photographic presentation at 100,000 magnification. Blaine fineness is greater than 40,000 cm^2/gm.

TABLE B

FLY ASH PROPERTIES

APRIL 1984

IDENTIFICATION	TEST	TYPE F CSA A23.5 SPECIFICATION
Carbons		
Carbonate	0.012%	--
TOTAL CARBONS	0.047%	--
Loss on Ignition	0.28%	12 maximum
Pozzolanic Activity With Cement (28 Day)	93.5%	75 minimum
Relative Density	2.12	--
Fineness 45 um	12.5%	34 maximum
Blaine Fineness (cm^2/gm)	3,850	--
Sulphur Trioxide	0.26%	5.0 maximum
Oxides		
Silicon	58	--
Aluminum	20	--
Iron	11	--
TOTAL OXIDES	89	75 (recommended minimum)

TABLE C

SKW MONTREAL SILICA PROPERTIES

IDENTIFICATION	% TEST	% MAXIMUM NORSEP STANDARDS
Silicon Dioxide	92%	---
Carbon	1.0%	2.0
Fe_2O_3	0.8	2.0
Al_2O_3	0.3	1.4
Calcium Oxide	1.0	---

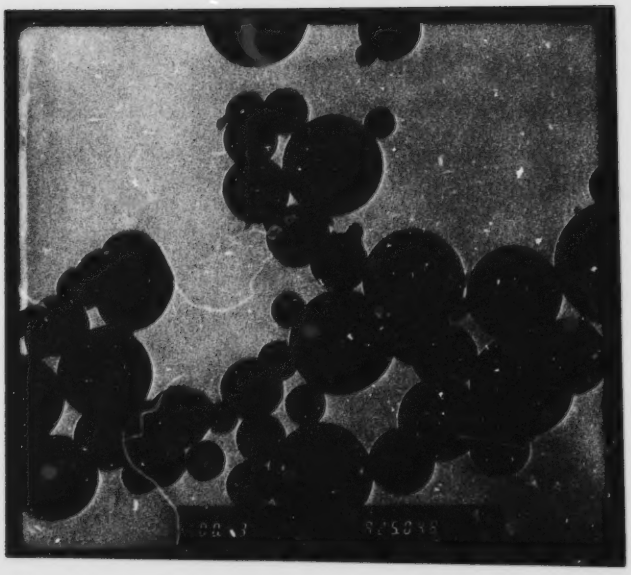

FIGURE 1

Pozzolanic activity of SKW fume with cement (28 days) was 90% of control with no dispersing agent at a water demand of 165% for equal flow.

E. Fine Aggregate

The fine aggregate source selected for the trials was Friday Harbour, the same material employed in the Tarsuit caissons. The sand is a blended product with conventional concrete sand and 5 X 1.25 mm birdseye added. The resultant grain size is detailed on Figure 1 of Appendix 2.

Additional fine aggregate properties include:

- magnesium sulphate loss	4.1%
- Organic Number	No. 1
- Relative Density	2.76
- Water Absorption	1.1%

F. Coarse Aggregates

Three coarse aggregates were employed, a standard-mass aggregate as a reference and two Canadian expanded-shale lightweight aggregates (rotary kiln process).

1. Standard-Mass Aggregate

Friday Harbour source, 12.5 mm X 5 mm. The grain size of the material is detailed on Figure 2 of Appendix 2.

Other physical properties include:

- Los Angeles Abrasion (C131-A)	11.2%
- CSA Petrographic No.	112.2
- Fracture (one face)	5.0%
- ASTM C289 Chemical Alkali Reactivity	innocuous
- Magnesium-Sulphate Loss	2.4%
- Relative Density	2.80
- Water Absorption	0.8%

Material may be described as subrounded and very clean, with no measurable flat or elongated particles.

This aggregate source has a track record of performance in high-strength industrial standard-mass ready-mix and precast concretes at Vancouver, B.C.

2. Herculite

This lightweight aggregate is a trade name of Consolidated Concrete of Calgary, Alberta. The source was used in the construction of Tarsuit caissons in 1981.

The grain size distribution for the material is shown in Figure 3 of Appendix 2. The manufactured product is an uncrushed, expanded shale. The general particle shape is subrounded.

The received moisture content of the lightweight aggregate averaged 3.6%. The relative density was 1.71. A series of absorption tests was carried out on blended samples to ascertain the effect of time for water contact to achieve 70% or greater absorption(1). A summary of results follows in Table D.

These results indicate that the significance of immersion beyond 5 minutes is not dictated by a magnitude of improvement in saturation. These results were considered in the establishment of mixing cycles and techniques.

The dry unit mass of this coarse aggregate is 810 kg/m^3.

The freeze/thaw durability of Tarsuit caissons employing the Herculite product at 45 MPa strength levels has been touched on in the previous report. After three winters in the high Arctic, the performance of shell concretes has been described by P.T. Seabrook as excellent.

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(1) Technology of lightweight concrete suggests that the optimum moisture content for maximum strength is greater than 70%, which limits the mixing water absorption by the aggregate.

TABLE D

HERCULITE WATER ABSORPTION VERSUS TIME

19°C INVESTIGATION

IMMERSION TIME	SSD ABSORPTION (%)
1 Minute	7.0
2 Minutes	7.0
5 Minutes	8.0
10 Minutes	7.4
1 Hour	7.5
5 Hours	8.1
24 Hours	8.2

NOTE: (personal communication). Anomalous, high early-absorption values discussed with H. Robinson, of ESCSI, who has seen similar performance for this generic lightweight aggregate type.

3. Avon Aggregates

Avon Aggregatee from Moncton, New Brunswick, was selected as a second source of lightweights. The unit mass dry of the material is measured at 790 kg/m^3 and the relative density 1.66.

The material has been employed in precast-prestress concrete construction and has a developed track record of durability in exterior freeze/thaw environments (personal communication, H. Wilson, P.Eng., of CANMET).

The material presents a unique grey appearance, and particles are subangular to subrounded. Crushing is, however, not employed in the manufacturing process.

Absorption testing, as employed in the time-immersion study on Herculite was undertaken with the Avon product. Results were as follows on Table E.

The received moisture content of the mixed sample averaged 11.9%. Owing to these writers' lack of familiarity with the Avon aggregate, it was analyzed chemically. Principal chemical constituents of the aggregate by Argon Plasma Assessment included those indicated on Table F.

G. Chemical Admixture Systems

1. General

Two systems of chemical admixture were used in the trials. To avoid incompatibility, the products were not "mixed" between manufacturers. The two selected were:

(a) Masterbuilders Products
- Low-range reducer/retarder: Pozzolith 100XR
- Air-entrainment agent: neutralized vinsol resin
- High-range water reducer extended-window superplasticizer: SP847

TABLE E

AVON AGGREGATE WATER ABSORPTION VERSUS TIME

19°C INVESTIGATION

IMMERSION TIME	SSD ABSORPTION (%)
1 Minute	14.2
2 Minutes	14.7
5 Minutes	14.4
24 Hours	14.2

Note: See Table D, Page 12.

TABLE F

AVON AGGREGATE MAJOR CHEMICAL CONSTITUENTS

Silicon Dioxide	61%
Oxides	
Aluminum	21
Iron	10
Magnesium	2
Calcium	1
Potassium	4

(b) Grace Construction Products

- Low-range reducer: Daratard 17
- Air-entrainment agent: neutralized vinsol resin
- High-range water reducer extended-window superplasticizer: Daracem DX 100

2. Masterbuilders Products

The products employed in the trials meet the requirements of CSA A266.1 and A266.2 as required. Products obtained were tested to confirm physical and chemical properties yielding those shown in Table G.

3. Grace Construction Products

Materials meet the existing demands of CSA Standards and have a demonstrated track record in the production of high-strength concretes. As with Masterbuilders, submitted materials were chemically assessed (see Table G).

4. Discussion

All admixtures were from one shipment. The chlorine ion loading through admixtures, in the worst case, is less than 60 grams per metre of concrete.

High-range water-reducing admixtures are both modification of napthalene-formaldehyde condensates of the extended-window superplasticizing types. Without significant shift in the time of set, the products demonstrate 40% slump loss from initial value 2 hours after introduction. Conventional plasticizers lose the same slump in less than 1 hour.

Both manufacturers were consulted as to product selections and recommended dosages. They participated in initial trials and their assistance was of value. A decision was made that, to be consistent with typical ready-mix supply, the maximum superplasticizer dosage would be the limit recommended by each supplier.

TABLE G

ADMIXTURE PROPERTIES

APRIL 1984

	SOLIDS	SPECIFIC GRAVITY	Cl ION
Masterbuilders			
NVR	22%	--	--
100XR	48%	1.216	0.03%
SP 847	41%	1.211	0.05%
Grace Products			
Daravair	20.5%	--	--
Daratard 17	49%	1.240	0.15%
Daracem DX100	40.0%	1.213	0.09%

IV. PROPORTIONING OF CONSTITUENTS

Drawing upon the strength development history of the high-strength, semilightweight concrete employed in the construction of the Tarsuit Atoll in 1981 and preliminary test mix results presented in our report on Phase I of the program, ranges of constituent values were assigned prior to formal proportioning.

For cementitious content, the range was between 450 and 550 kilograms per cubic metre. The quantities are mitigated by a desire to severely restrict drying shrinkage, optimize the development of both compressive and tensile strength, and to minimize heat development. It has been kept in mind that the field application of the concrete proposed must accommodate placements whose least dimension is in excess of 1.5 metres.

Thermal history work done by Mr. M.E. Roberts-Seymour, P.Eng., for the SSDC Shell concrete placed at Osaka, Japan (Hitachi Zosen), showed that even low tricalcium-aluminum cements (Type 50), when unaided by fly ash substitutions, provided unsuitably high temperatures in the initial 48 hours of curing. For plastic concrete temperature of 20°C, in-form temperatures of 85°C were encountered in 1.3 metre least dimension elements at Type 50 cement contents of 490 kg/m^3. It is, therefore, essential to reduce thermal gain through judicious replacement of normal portland cement with fly ash.

The range of fly ash replacements studied in connection with this trial program is 0%, 12.5%, and 25% of the mass of cementitious. Mitigating the replacement value is both a desire to optimize strength performance at 91 days and to appreciate a significant workability contribution from the spherical nature of the particles of fly ash.

Lightweight particle size selection was predicated on precast performance-size histories coupled with the intent to use the product in highly congested reinforced sections in a flowable state. It is desirable to maintain lightweight close to 0.4 cubic metres absolute

volume per metre of mixture (to minimize drying shrinkage through optimal volume stability).

B.H. Levelton & Associates Ltd.'s experience with North American lightweights has been, generally, that heavier expanded clay/shales provide higher compressive strengths. It has been considered desirable to maintain the threshold of hardened dry unit mass of resulting concrete below 2,000 kg/m^3 and idealize it at 1,900 kg/m^3.

Fine aggregate proportioning has been held closely to absolute volumes of 0.24 m^3, consistent with a minimum to optimize strength without sacrificing rheological suitability. The sand is subrounded and has a fairly high relative density(1).

Air content for trial mixtures was targeted to 3.0%, accounting for the low water : cement ratios planned in connection with superplasticizer systems. Planning on water : cementitious levels of significantly less than 0.35, air contents of 3.0%, freezable water below 1.5%, and spacing factors lower than 440 um, suitable freeze-thaw durability has been assumed(2).

Results of very recent freeze-thaw tests (ASTM C666, Procedure A) conducted as part of high-strength, semilightweight and normal-weight concrete development for Arctic structure development (work by Porland Cement Association and also by Abam Engineering) show that air contents in the 3% to 4% range can provide excellent durability. It appears that the required air content is proportional to the water : cement ratio. For values less than 0.35 here, the 3% design air content should be satisfactory.

Water demand adjustments vary with admixtures. Fly ash substitution requires adjustment to provide equal workability, and silica fume increases water demand. It is targeted in the preparation

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(1) Accepting that suitably durable sand in the relative density range of 2.6 might be available with similar grain size characteristics, unit masses might be decreased by as much as 30 kg/m^3 over those associated with these trials.

(2) Malhotra; "Mechanical Properties and Freeze/Thaw Resistance of Superplasticized Concrete"; Cement, Concrete, and Aggregates; Summer 82; ASTM Philadelphia; Table 17.

of designs to hold water : cementitious ratios close to 0.35 using the extended-window superplasticizers low-range retardant. The maximum addition rate limitations prescribed by the manufacturers have been employed. For 450 kg/m^3 of cementitious, this sets a threshold of 144 litres of water per cubic metre. Allowance in proportioning has also been made for the volume of chemical admixtures used.

Detailed mix proportions are presented on Tables 1.A, 1.B, and 1.C of Appendix 1.

V. BATCHING AND MIXING

A. Mixing Considerations

Several informal trial batches were undertaken to examine charging and mixing sequence alterations adaptable to the materials here.

In all cases, an 0.08 m^3 mix was charged into a variable pitch-fin drum mixer. The intent throughout the trial program has been, as closely as possible, to replicate the capabilities of conventional transit mix concrete delivery.

Silica fume posed a significant challenge. When charged to the mixer as a dry solid (i.e. with fly ash), cut sections of hardened concrete specimens revealed a tendency of particles to remain agglomerated. This assessment was made simple by the radical colour variations between the portland cement, ash, and SKW Montreal silica fume used.

To solve the distribution problem, it is necessary to mix the silica fume with both water and a high-range water-reducer dispersant. To do so, all plasticizers and 10% of mixing water were required for the most heavily loaded silica fume designs. Using as a limitation, the highest superplasticizer dosage (recommended by the manufacturer), in-place water of retempering was used to bring concrete to minimum flowable slump standards. For consistency, all mixes were treated in this fashion--the silica fume dispersion controlling the processes.

In contrast to conventional structural concrete practice where high-range water-reducer dosage is adjusted, these materials require the water dosage be adjusted. Superplasticizer dosage is held constant as volume ratio of gross cementing content. For all trials across both admixture systems, 1,200 ml/100 kg of gross cementitious was used.

B. Mixing Procedures

The mixing procedure developed from CSA A23.2-12C was:

1. Charge 50% of the coarse aggregate (in lightweight mixes, water had been added to account the deficit between 100% saturation and the as-weighed moisture content, and mixing undertaken for 5 minutes prior to commencement of charging. See text Reference III, F, 2) and 3) regarding absorption-time relationships);
2. Batch 50% of cement;
3. Batch 100% of fly ash;
4. Batch 100% of sand;
5. Add 70% of estimated mix water together with low-range water reducer;
6. Prepare a slurry of silica fume together with gross superplasticer dosage;
7. Charge slurry;
8. Mix for 5 minutes;
9. Add 5% of mix water together with air-entraining admixture;
10. Add balance of solids;
11. Retemper with water to target slump.

VI. TESTING PROGRAM

The general outline of testing requirements is presented in the Phase I report. Specific test sequences and methods are outlined in Table H.

A. Hardened Concrete

Compressive test specimens were stripped at 48 hours. At 24 hours, gross retardation of the concrete in most mixes prevented stripping since sensitive green material either broke or ravelled. Compressive specimens were then placed in lime-saturated water bath curing tanks until testing.

B. Comments Upon Mixing, Fabrication, and Selection of Testing Methods

This program is undertaken within the mandate that technology developed reflect the existing and immediate capacities of transit mixer ready-mix concrete production. An adjunct is the transfer of standard concrete testing procedures to its quantification.

Terms of reference here do not encourage some mixing and testing refinements that would improve properties. Available alternative techniques and their probable resultant affects on the technology would include:

- Quench preparation of lightweight aggregate (less sensitivity to mix water requirements, higher unit mass, improved compressive strength);
- Vacuum preparation of lightweights (with same anticipated benefications as quench treatment);
- Vibration of test specimens (higher strengths than rodding, higher indicated unit mass);
- Revibration lift sequences for test specimens (i.e. vibrate, rest 20 minutes, then revibrate each lift) (higher strengths, higher indicated unit mass);

TABLE H

TEST PROCEDURES

TEST	PROCEDURE	NOTES
A. Plastic Properties		
Air Content		
- Normal Weight	CAN3-A23.2-4C	Pressure
- Lightweight	CAN3-A23.2-7C	Volumetric
Unit Mass	CAN3-A23.2-6C	7 L vessel
Slump	CAN3-A23.2-5C	
B. Hardened Concrete Samples		
Compressive Strength	CAN3-A23.2-3C	100 mm X 200 mm tin molds consolidate by rodding, cure continuously @ 23°C, fog room for 48 hours, lime water bath after
Unit Mass	ASTM C567	Set A of split tensile tests below were used
Split Tensile	CAN3-A23.2-3C	150 mm X 300 mm cylinders vary curring as: Set A - 7 day water, 21 days lab air Set B - 7 day water, 84 day lab air
C. Strength Testing		
Compression	CAN3-A23.2-9C	High-strength capping compound; test 2 @ 7, 2 @ 28, and 2 @ 91 days
Split Tensile	ASTM C496	

- Employment of thick wall steel moulds in cylinder preparation (anticipating higher strength tests);
- Fine aggregate treatment by sand-enveloped cement system (higher strength);
- Superplasticizer dose and redose introduction at varying times in the mixing cycle;
- Refinement of curing cycle to incorporate low-temperature initial cure and stepped increase in cure temperature to 91-day age maturity (higher ultimate strength);
- Triaxial testing and/or service life temperature testing of hardened concrete to imitate in-place conditions (significantly higher strength, especially in cryogenic service conditions);
- Nonflowing concrete to further reduce water : cementitious ratio (higher strength, lower permeability);
- Use of formate, nitrite, or thiocyanate accelerators to offset retarding effects;
- Changes in mixer type, vane velocity. and/or mixing time.

VII. PLASTIC PROPERTIES OF CONCRETE TRIALS

Mixing was undertaken during the period April 6 through May 4, 1984. Between 6 and 12 mixes per day were batched.

Plastic properties of all 162 trial mixes are detailed on Tables 2.A to 2.C of Appendix 1. They may be summarized as follows:

- Yield of mixtures was between 0.99 and 1.02;
- Plastic temperature of all concrete mixtures was between 17°C and 19°C;
- The unit mass of plastic concrete did not exceed:
  - 2,470 kg/m^3 for standard mass,
  - 2,010 kg/m^3 for Herculite,
  - 2,010 kg/m^3 for Avon Aggregates;
- Air contents of trial mixtures fell between 2.4% and 5.8%. This property was difficult to control in mixing. Small variations of neutralized vinsol resin in a 0.08 m^3 batch increased measured air contents by 2%. However, by far, the majority of all mixes lie within a 0.5% tolerance of the target 3.0% design. No de-airing was permitted;
- Water : cementitious ratios for trials were between 0.21 and 0.35, with highest values being observed in standard-mass batches and lowest in Avon Aggregate batching.

All mixes had a slightly harsh appearance, with those involving the more angular Avon materials being most notable in this regard. All demonstrated suitable characteristics of workability for the fabrication of test specimens and good response to insertion (pencil) vibration.

VIII. HARDENED CONCRETE PROPERTIES

Properties of hardened concrete are detailed in Tables 3.A to 3.C of Appendix 1.

Dry, hardened unit mass of concrete ranged:

- between 2,360 and 2,505 kg/m^3 for standard-mass aggregates;
- between 1,960 and 2,050 kg/m^3 for Herculite aggregates;
- between 1,840 and 2,050 kg/m^3 for Avon aggregates.

Split tensile strengths at 91 days for lightweights were on the order of 5.5% of the compressive strength (lower than the 7% anticipated). Specimen split tensile samples continuously water cured for 91 days yielded predictably higher results than did those cured 7 days in water and 84 days in lab air. The increase was between 10% and 30%. The target design 5 MPa split tensile strength was achieved in several mixtures from the standard mass series. However, the highest 91-day wet tensile for Herculite was 4.6 MPa, with most mixtures in th 4.0 MPa range. Avon aggregate trials behave only marginally better in this regard.

Compressive test data is presented for 7, 28, and 91 days, respectively.

As noted in the May 15, 1984, interim mixing report, 7-day data for mixtures present very low comparative strengths for those mixtures in the 25% fly ash replacement series. The low strengths (some below 5 MPa at 7 days) result from the gross retardation effect of chemical admixtures complimented by the reduced content of portland cement (i.e. 265 kg/m^3 cement in some cases). Strength appears to accelerate rapidly when the retardation effect is depleted.

Seven-day data are not considered as suitable for comparison between trial mixtures. The temperature maturity of the specimens is unequal, even though the real time course is equal. It is concluded that this phenomenon is overcome by the aging of specimens at 23°C through 91 days.

An important impact of the radically low maturity development of both 12.5% ash series and 25% ash series is felt on the probable need in real construction for "early" post tensioning. Low post-tensioning stress requirements (i.e. 3 MPa) have previously been required, but the recent tendency of structural authorities is to demand higher values as early as three days from time of cast. This notable feature will require a trade-off, since trial mixes clearly point to best ultimate (91-day design age) strengths through the use of pozzolanic substitutions equal or greater than 12.5%.

Air content variances in trial mixing must be adjusted for direct comparison purposes. Using procedures developed and reported upon by D.R. Morgan, P.Eng., R.M. Hardy & Associates Ltd., from his high-strength concrete experience coupled with PCA, USBR, and Neville principles, a mechanism for adjusting strengths on a linear proportionality from a selected target entrainment is possible. All compressive data of these trials have been so reduced (or adjusted) as detailed on Tables 4.A to 4.C of Appendix 1.

Consolidating the compressive strength results of both Grace and Masterbuilders systems mixes on the basis that admixtures systems constituted the apparently least variable differing components of these trials, data are presented as Tables I to K following. Under each fly ash replacement system for a given gross cementitious content, values adjusted for air entrainment are presented in a form allowing standard mass, Avon, and Herculite performance to be quickly compared.

As indicated, the performance of the standard-mas series is considerably better in compression than either of the lightweights. Here, trends to improvement with increased fly ash replacement are the same as demonstrated in the lightweight series.

TABLE I

450 KILOGRAMS CEMENTITIOUS

AVERAGE 91 DAY COMPRESSIVE STRENGTH(1) SUMMARY

AGGREGATE TYPE	STANDARD MASS (MPa)	HERCULITE (MPa)	AVON (MPa)
A. 0% Flyash			
0% Silica	71.5	56.8	62.0
7.5% Silica	66.7	53.8	67.0
15% Silica	72.3	56.7	67.3
B. 12.5% Flyash			
0% Silica	64.0	55.3	59.8
7.5% Silica	76.6	64.2	65.6
15% Silica	77.0	58.1	59.0
C. 25% Flyash			
0% Silica	64.2	52.6	58.1
7.5% Silica	73.1	57.3	68.6
15% Silica	73.1	53.4	66.7

NOTE: (1) Corrected to Air Content 3%.

(2) Masterbuilders and Grace admixture sets averaged.

TABLE J

500 KILOGRAMS CEMENTITIOUS

AVERAGE 91 DAY COMPRESSIVE STRENGTH(1) SUMMARY

AGGREGATE TYPE	STANDARD MASS (MPa)	HERCULITE (MPa)	AVON (MPa)
A. 0% Flyash			
0% Silica	74.3	54.9	63.8
7.5% Silica	82.5	61.2	61.1
15% Silica	85.2	58.1	75.1
B. 12.5% Flyash			
0% Silica	67.3	54.4	65.2
7.5% Silica	80.0	67.9	62.1
15% Silica	75.0	59.6	69.3
C. 25% Flyash			
0% Silica	73.1	56.9	50.7
7.5% Silica	84.7	59.0	66.4
15% Silica	81.5	58.8	59.7

NOTE: (1) Corrected to Air Content 3%.

(2) Masterbuilders and Grace admixture sets averaged.

TABLE K

550 KILOGRAMS CEMENTITIOUS

AVERAGE 91 DAY COMPRESSIVE STRENGTH(1) SUMMARY

AGGREGATE TYPE	STANDARD MASS (MPa)	HERCULITE (MPa)	AVON (MPa)
A. 0% Flyash			
0% Silica	67.3	63.2	59.6
7.5% Silica	92.9	61.5	66.0
15% Silica	94.4	59.7	68.0
B. 12.5% Flyash			
0% Silica	68.0	59.2	56.5
7.5% Silica	100.5	62.0	67.3
15% Silica	92.5	58.6	63.1
C. 25% Flyash			
0% Silica	70.3	57.3	56.3
7.5% Silica	92.34	60.9	65.4
15% Silica	83.4	57.8	68.2

NOTE: (1) Corrected to Air Content 3%.

(2) Masterbuilders and Grace admixture sets averaged.

Generally, it is concluded that the 91-day strength boundaries for the three aggregates within the techniques of this program are:

- Standard mass 95 MPa[1];
- Avon Aggregate 75 MPa;
- Herculite 65 MPa.

For the lightweight mixtures, the optimal design as to strength is practically independent of the gross cementitious content in the 450 to 550 kg/m^3 range tested. This suggests that the threshold of either aggregate capacity or quantifying procedures is being tested. The tight bunching (taken as a percentage of strength) between all mixes highlights this conclusion:

- Avon mean 91 day 64 MPa for all mixes, one standard deviation 8% of mean;
- Herculite mean 91 day 58 MPa for all mixes, one standard deviation 6% of mean.

Considerably greater range is seen in standard-mass sequences with an increase in compressive strength at each step in gross cementitious from 450 to 550 kg/m^3.

The introduction of silica fume clearly improves 91-day strength performance. Optimal replacement rates probably lie between 7.5% and 15% by mass of gross cementitious, since a slight decrease in the potentiation of strength is observed in several series with the increase in fume above 7.5%. Correspondingly, there is a very slight benefication of splitting tensile strength with the incorporation of fume.

The small increase in compressive strength from 28 to 91 days amplifies the concern that the capacity of the aggregate or measurement of system may control the performance of lightweight systems at or above 70 MPa. In fact, a few 28 to 91-day maturities show a decrease in quantified strength with increase in specimen age, presumably an anomaly in the testing methods. Assessment of such an hypothesis might be

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(1) This compares favorably with Nolsiefer's, "Ultrahigh-Strength Field-Placeable Concrete With Silica Fume", Concrete International, April 1984.

obtained by using "nonstandard" mixing and/or testing practices to verify if further "gains" could be observed.

While cementitious mass increases within the limitations of this investigation showed no significant strength increases, freeze/thaw durability (and adjunct permeability and porosity) together with abrasion resistance may be more dramatically influenced by cementitious content. These properties will be assessed in Phase III.

IX. CONCLUSIONS

The following points have been concluded:

- Early strengths of ash-replaced mixtures when retardant water-reducing chemicals are used (to the extent in this program) are probably unsuitable for conventional post-tensioned construction practices;
- The achievement of 91-day acceptance of 65 MPa semilightweight portland cement concrete to existing ready-mix procedures is possible;
- Avon Aggregates (New Brunswick) presents the most promising performance from strength perspectives;
- Pursuit of gross cementitious contents above 550 kg/m^3 can not be justified from a review of strength performance in this program;
- Silica fume provides significant strength benefication in all tested concretes. The order of magnitude for as little as 7.5% portland cement replacement is 10 MPa benefication at the 91-day acceptance;
- Fly-ash replacements to 25% equal or improve upon the compressive strength performance of basic portland cement control concretes, 12.5% would appear close to optimal;
- A realistic dry unit mass of hardened concrete for those products and levels in this program would be targetted higher than 1,900 kg/m^3 to possibly 2,000 kg/m^3;
- The splitting tensile performance of all concretes tested was disappointing. A generally linear (rather than power fit)[1] relationship to compressive strength is suggested. However, the target of 5 MPa for these materials and techniques appears

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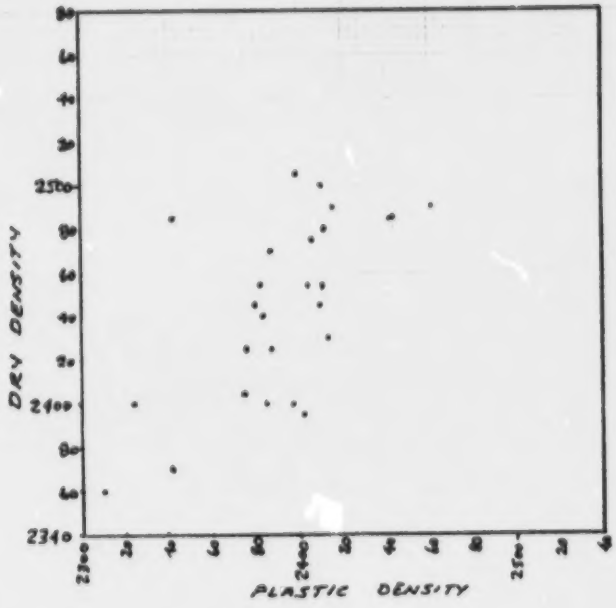
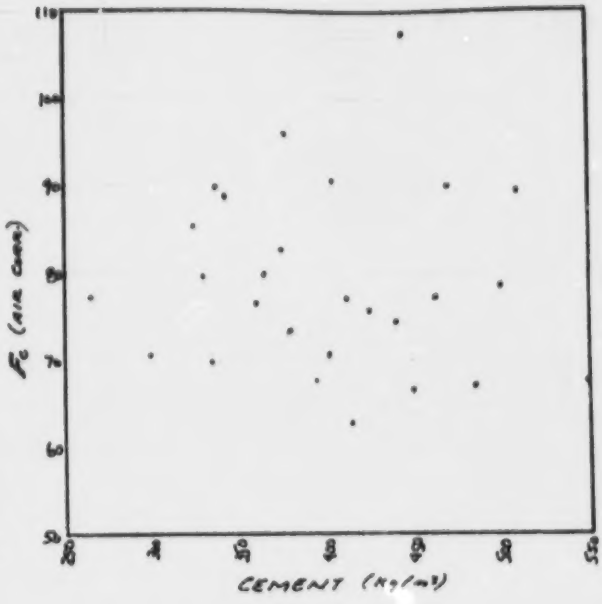
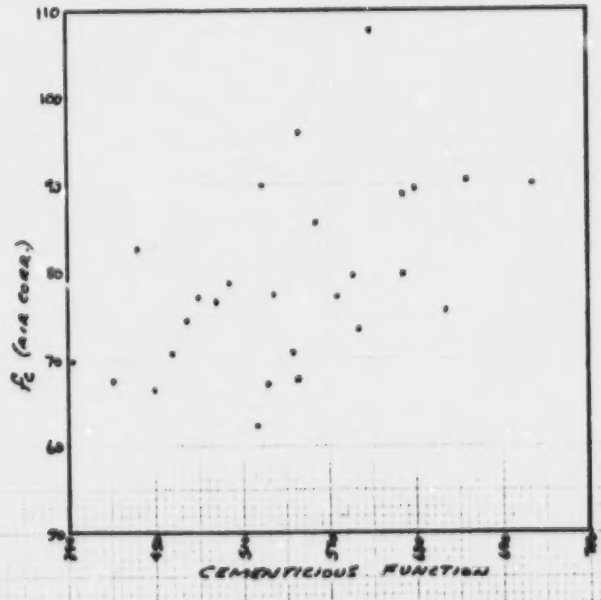
(1) Lalond as edited by these authors in "Development of Ultrahigh-Strength Concrete, Phase I, Background Data Assembly", (March 1984), Page 22.

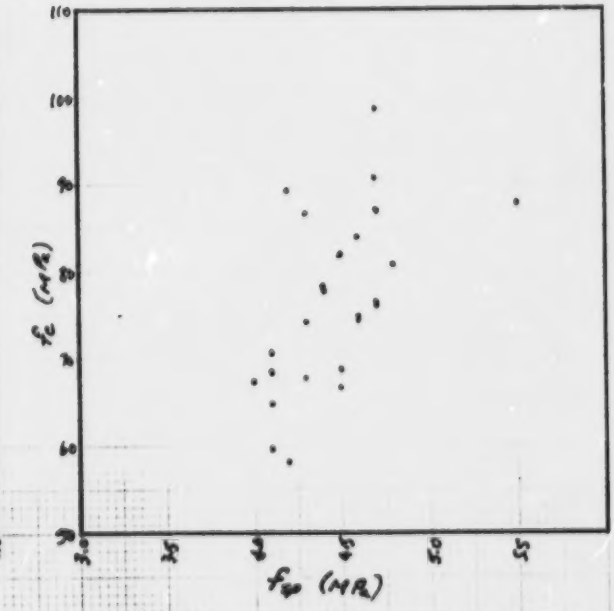
unrealistic. A 4.5 MPa upper limit would be considered a more responsible demand to make of the materials;

- Within test coefficients of variation for split tensile testing, do not improve by moving from air to full wet cure. However, universally higher test values are recorded for wet sample testing. This is more in keeping with service life conditions of Arctic marine concrete;
- Further testing should predicate the time of testing of all strength specimens on the actual temperature maturity of the specimens measured by integrating thermistor equipment;
- Less than desirable ratio of split tensile to compressive strengths observed here may be attributable, in part, to silica fume inclusion (after Jahren SP79, see Phase I report);
- Future programs may experiment with nonlignin, low-range water-reducer retardants in the presence of silica fume to offset retardation/slump interface difficulties;
- Tensile strengths might be carried to target 5 MPa levels through the limited incorporation of steel or polypropylene fibres, inclusion of which was not part of this program;
- There is no acceptable correlation between dry hardened unit mass of lightweight and compressive strength was noted;
- Ninety-one day air-adjusted concrete compression values are too tightly bunched for any meaningful water : cementitious to strength relationship assessment.









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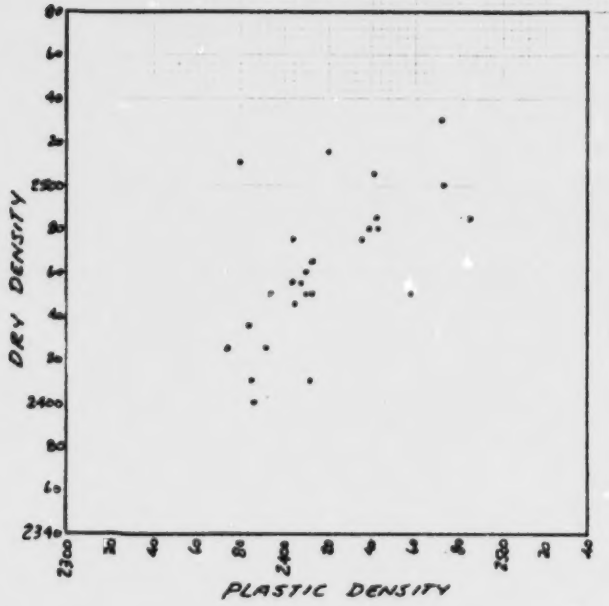

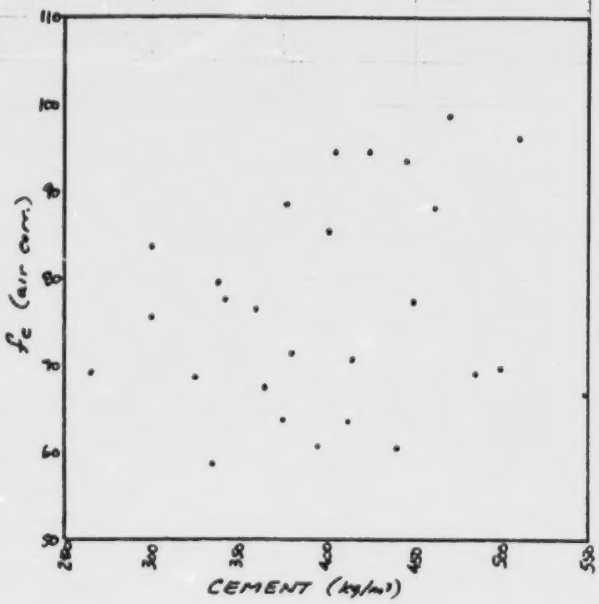

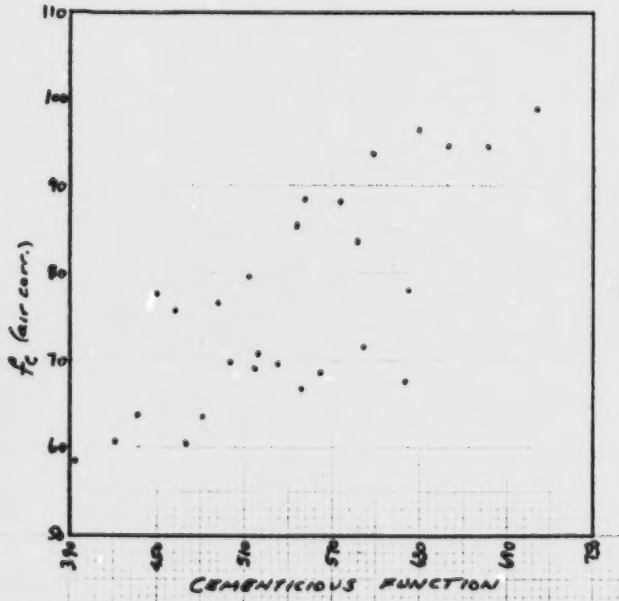

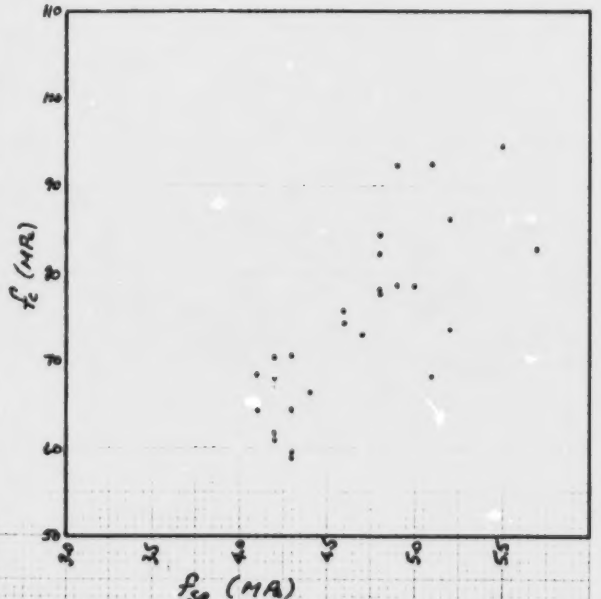

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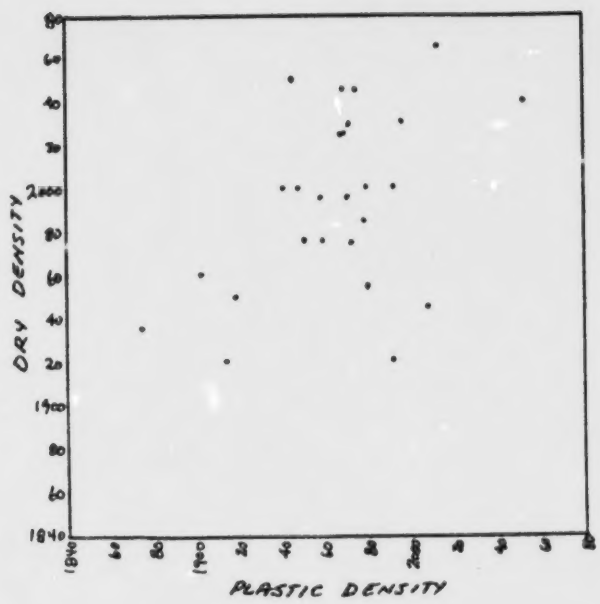

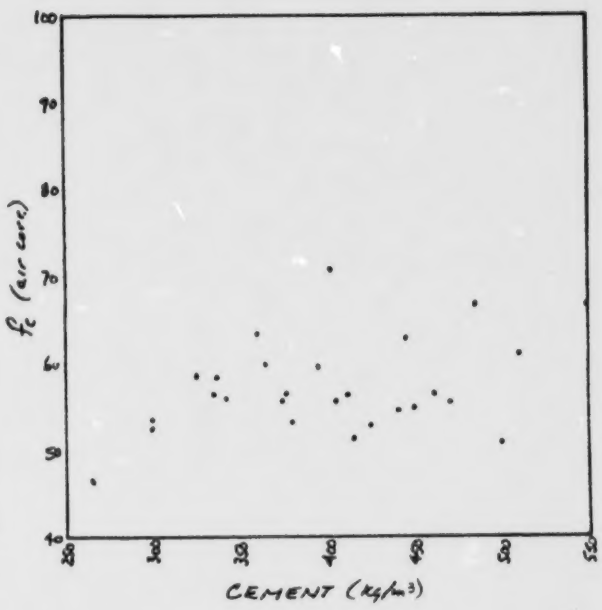

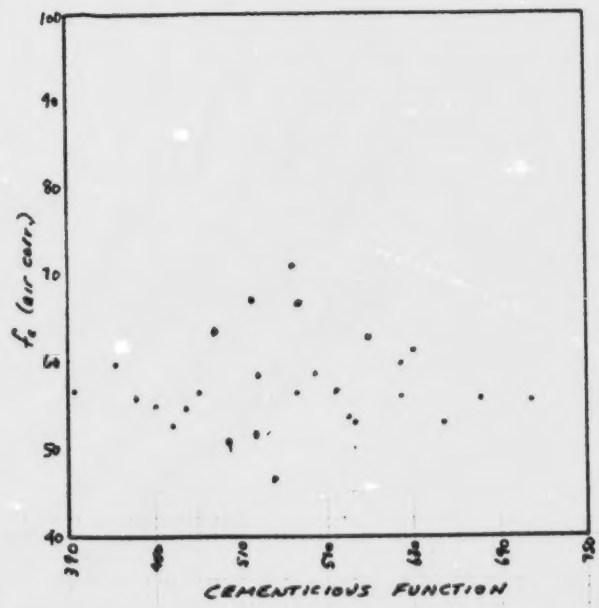

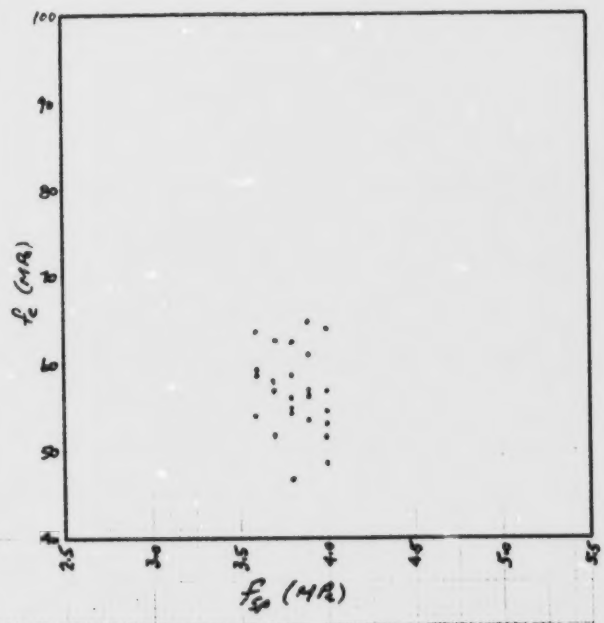

HERCOLITE AGGREGATE

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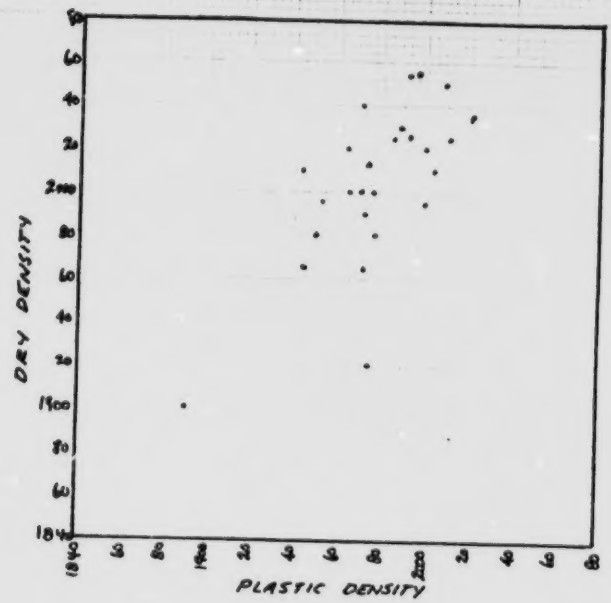
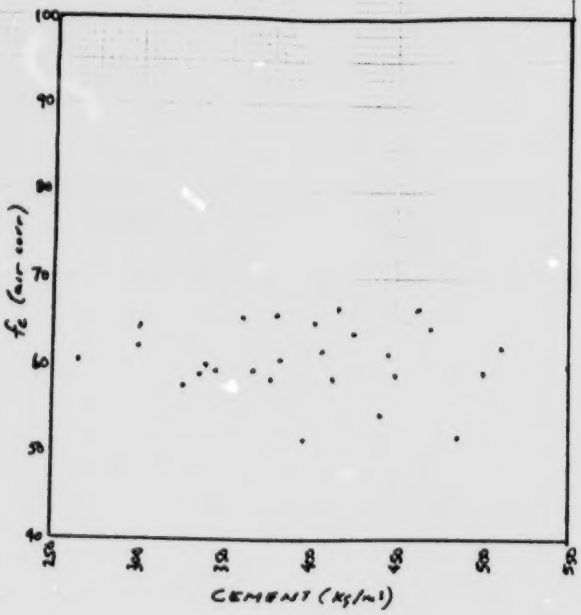
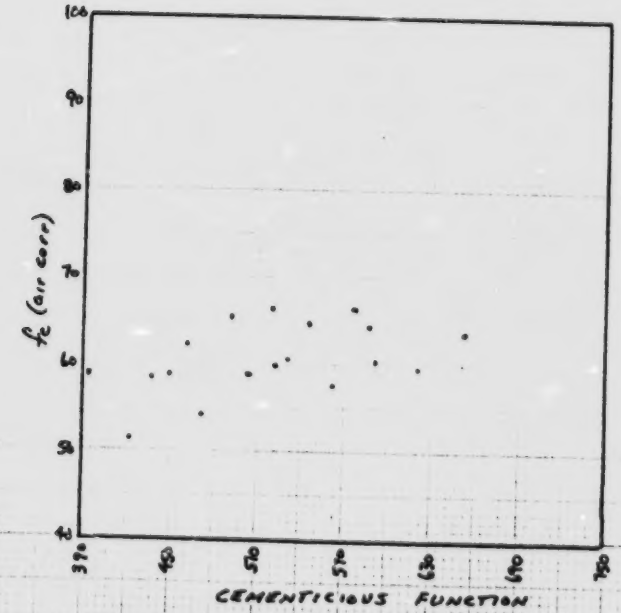
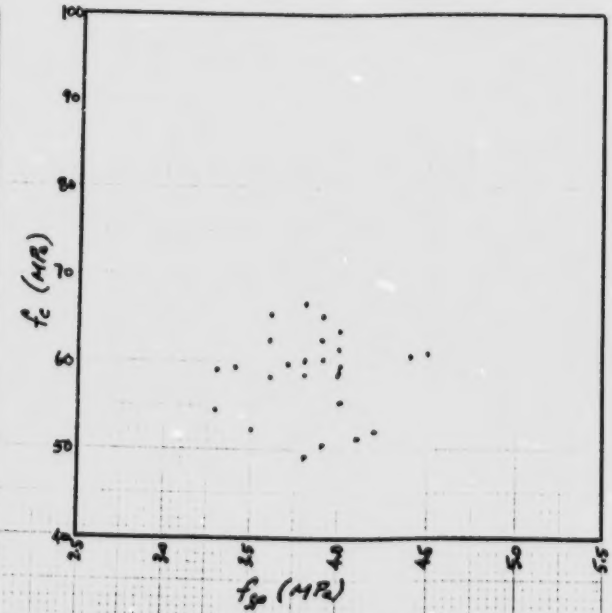


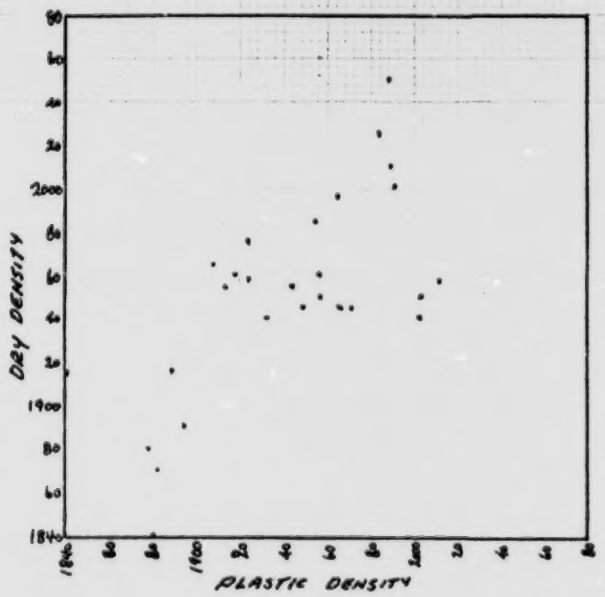


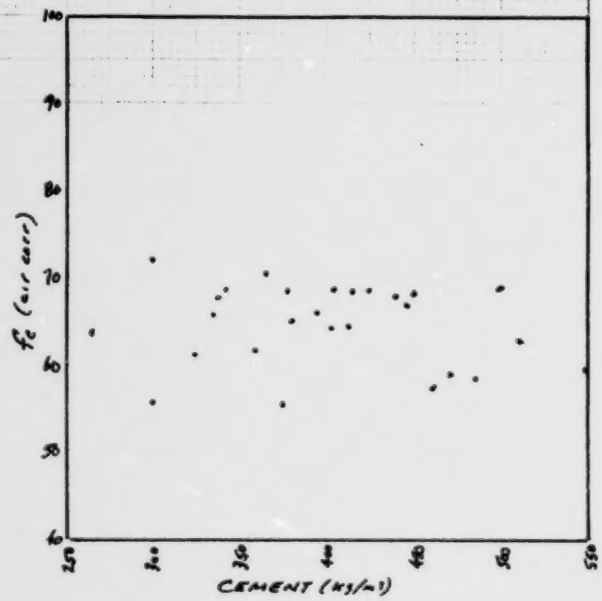


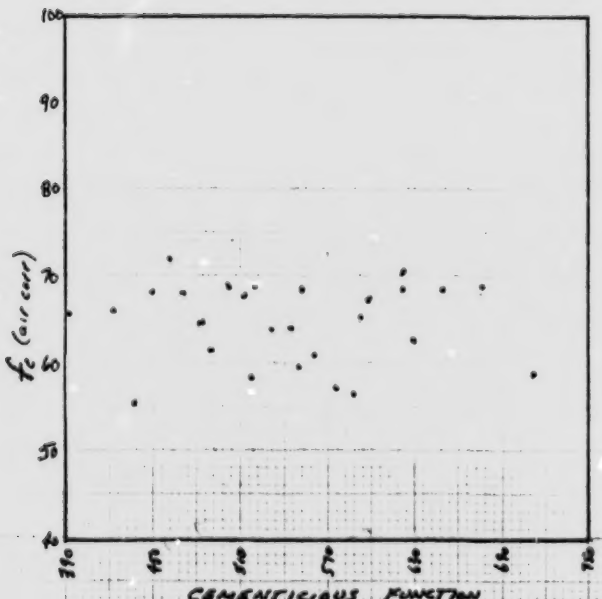


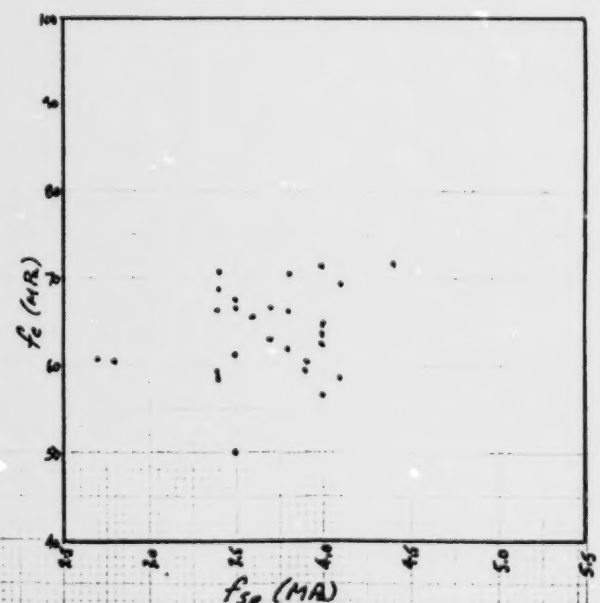
HERCOLITE AGGREGATE

- MASTER BUILDERS ADMIXTURES -









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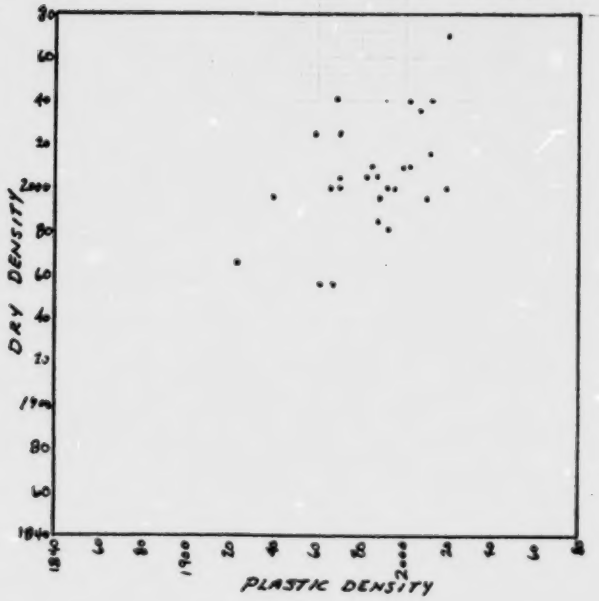
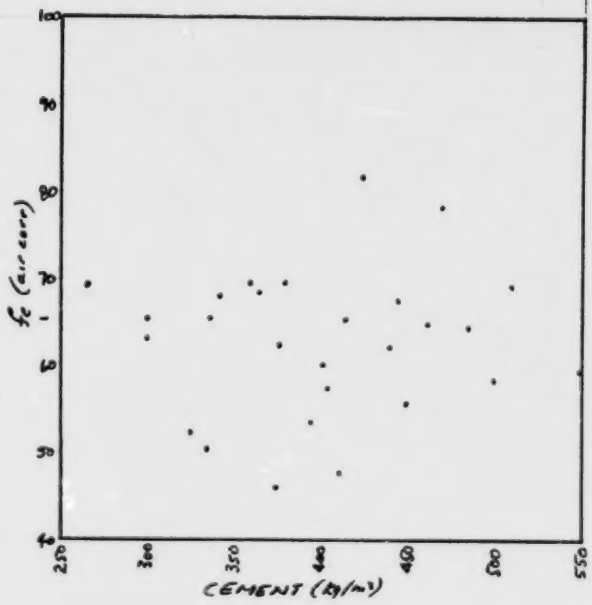
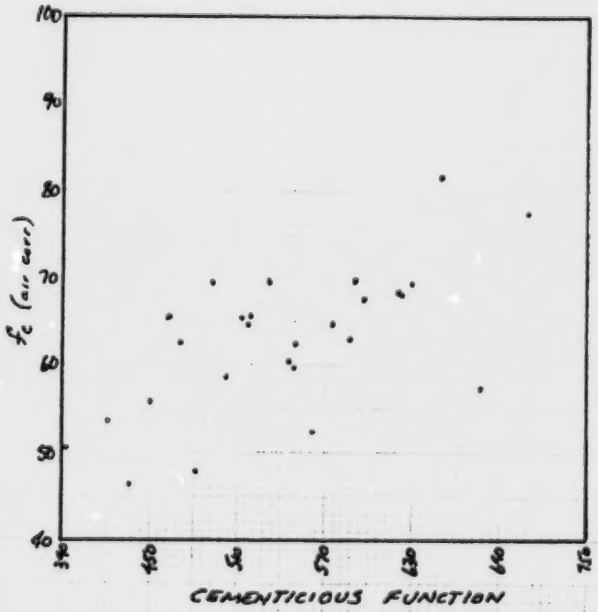
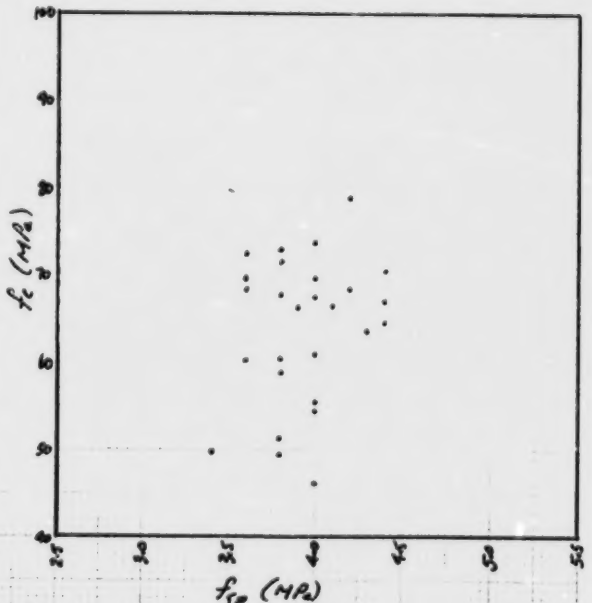








AVON AGGREGATE
- MASTER BUILDERS ADDITIVES -

APPENDIX 1

TRIAL MIXES

Table 1.A.1

Standard Weight Aggregates

450 kg/m^3 Cementitious

Primary Mix Designs(1)

Mix No.(2)	Cement kg/m^3	Flyash kg/m^3	Silica kg/m^3	Coarse kg/m^3	Sand kg/m^3
1,2	450	0	0	1160	700
7,8	415	0	35	1150	700
13,14	380	0	70	1130	700
19,20	395	55	0	1140	700
25,26	360	55	35	1130	700
31,32	325	55	70	1110	700
37,38	335	115	0	1110	700
43,44	300	115	35	1100	700
49,50	265	115	70	1090	700

Note: (1) Design Plastic Features
(a) Target Slump 180 mm
(b) Target Air Content 3.0%
(2) Admixtures
(a) Odd Numbered Mixes Grace Daratard 17
Low Range 300 ml/100 kg cementitious
Grace Daracem DX100 HRWRA 1200 ml/100 kg cementitious
or (b) Even Numbered Mixes Masterbuilders 100XR
Low Range 150 ml/100 kg cementitious
Masterbuilders PS847 HRWRA 1200 ml/100 kg

Table 1.A.2

Standard Weight Aggregates

500 kg/m^3 Cementitious

Primary Mix Designs(1)

Mix No.(2)	Cement kg/m^3	Flyash kg/m^3	Silica kg/m^3	Coarse kg/m^3	Sand kg/m^3
55,56	500	0	0	1120	685
61,62	462	0	38	1110	685
67,68	425	0	75	1110	685
73,74	440	60	0	1100	685
79,80	402	60	38	1090	685
85,86	365	60	75	1080	685
91,92	375	125	0	1070	685
97,98	337	125	38	1060	685
103,104	300	125	75	1050	685

Note: (1) Design Plastic Features
(a) Target Slump 180 mm
(b) Target Air Content 3.0%

(2) Admixtures
(a) Odd Numbered Mixes Grace Daratard 17
Low Range 300 ml/100 kg cementitious
Grace Daracem DX100 HRWRA 1200 ml/100 kg cementitious

or (b) Even Numbered Mixes Masterbuilders 100XR
Low Range 150 ml/100 kg cementitious
Masterbuilders PS847 HRWRA 1200 ml/100 kg

Table 1.A.3

Standard Weight Aggregates

550 kg/m^3 Cementitious

Primary Mix Designs(1)

Mix No.(2)	Cement kg/m^3	Flyash kg/m^3	Silica kg/m^3	Coarse kg/m^3	Sand kg/m^3
109,110	550	0	0	1090	670
115,116	510	0	40	1080	670
121,122	470	0	80	1070	670
127,128	485	65	0	1060	670
133,134	445	65	40	1060	670
139,140	405	65	80	1040	670
145,146	412	138	0	1040	670
151,152	377	138	35	1020	670
157,158	342	138	70	1020	670

Note: (1) Design Plastic Features
(a) Target Slump 180 mm
(b) Target Air Content 3.0%

(2) Admixtures
(a) Odd Numbered Mixes Grace Daratard 17
Low Range 300 ml/100 kg cementitious
Grace Daracem DX100 HRWRA 1200 ml/100 kg cementitious

or (b) Even Numbered Mixes Masterbuilders 100XR
Low Range 150 ml/100 kg cementitious
Masterbuilders PS847 HRWRA 1200 ml/100 kg

Table 1.B.1

Herculite Aggregates

450 kg/m^3 Cementitious

Primary Mix Designs(1)

Mix No.(2)	Cement kg/m^3	Flyash kg/m^3	Silica kg/m^3	Coarse kg/m^3	Sand kg/m^3
5,6	450	0	0	700	700
11,12	415	0	35	690	700
17,18	380	0	70	680	700
23,24	395	55	0	690	700
29,30	360	55	35	680	700
35,36	325	55	70	670	700
41,42	335	115	0	670	700
47,48	300	115	35	665	700
53,54	265	115	70	660	700

Note: (1) Design Plastic Features
(a) Target Slump 180 mm
(b) Target Air Content 3.0%

(2) Admixtures
(a) Odd Numbered Mixes Grace Daratard 17
Low Range 300 ml/100 kg cementitious
Grace Daracem DX100 HRWRA 1200 ml/100 kg cementitious

or (b) Even Numbered Mixes Masterbuilders 100XR
Low Range 150 ml/100 kg cementitious
Masterbuilders PS847 HRWRA 1200 ml/100 kg

Table 1.B.2

Herculite Aggregates

500 kg/m^3 Cementitious

Primary Mix Designs(1)

Mix No.(2)	Cement kg/m^3	Flyash kg/m^3	Silica kg/m^3	Coarse kg/m^3	Sand kg/m^3
59,60	500	0	0	680	685
65,66	462	0	38	670	685
71,72	425	0	75	665	685
77,78	440	60	0	665	685
83,84	402	60	38	660	685
89,90	365	60	75	650	685
95,96	375	125	0	650	685
101,102	337	125	38	640	685
107,108	300	125	75	635	685

Note: (1) Design Plastic Features
(a) Target Slump 180 mm
(b) Target Air Content 3.0%

(2) Admixtures
(a) Odd Numbered Mixes Grace Daratard 17
Low Range 300 ml/100 kg cementitious
Grace Daracem DX100 HRWRA 1200 ml/100 kg cementitious

or (b) Even Numbered Mixes Masterbuilders 100XR
Low Range 150 ml/100 kg cementitious
Masterbuilders PS847 HRWRA 1200 ml/100 kg

Table 1.B.3

Herculite Aggregates

550 kg/m^3 Cementitious

Primary Mix Designs(1)

Mix No.(2)	Cement kg/m^3	Flyash kg/m^3	Silica kg/m^3	Coarse kg/m^3	Sand kg/m^3
113,114	550	0	0	660	670
119,120	510	0	40	650	670
125,126	470	0	80	650	670
131,132	485	65	0	640	670
137,138	445	65	40	640	670
143,144	405	65	80	630	670
149,150	412	138	0	635	670
155,156	377	138	35	620	670
161,162	342	138	70	620	670

Note: (1) Design Plastic Features
(a) Target Slump 180 mm
(b) Target Air Content 3.0%

(2) Admixtures
(a) Odd Numbered Mixes Grace Daratard 17
Low Range 300 ml/100 kg cementitious
Grace Daracem DX100 HRWRA 1200 ml/100 kg cementitious

or (b) Even Numbered Mixes Masterbuilders 100XR
Low Range 150 ml/100 kg cementitious
Masterbuilders PS847 HRWRA 1200 ml/100 kg

Table 1.C.1

Avon Aggregates

450 kg/m^3 Cementitious

Primary Mix Designs(1)

Mix No.(2)	Cement kg/m^3	Flyash kg/m^3	Silica kg/m^3	Coarse kg/m^3	Sand kg/m^3
3,4	450	0	0	635	700
9,10	415	0	35	630	700
15,16	380	0	70	625	700
21,22	395	55	0	630	700
27,28	360	55	35	625	700
33,34	325	55	70	640	700
39,40	335	115	0	640	700
45,46	300	115	35	635	700
51,52	265	115	70	630	700

Note: (1) Design Plastic Features
(a) Target Slump 180 mm
(b) Target Air Content 3.0%

(2) Admixtures
(a) Odd Numbered Mixes Grace Daratard 17
Low Range 300 ml/100 kg cementitious
Grace Daracem DX100 HRWRA 1200 ml/100 kg cementitious

or (b) Even Numbered Mixes Masterbuilders 100XR
Low Range 150 ml/100 kg cementitious
Masterbuilders PS847 HRWRA 1200 ml/100 kg

Table 1.C.2

Avon Aggregates

500 kg/m^3 Cementitious

Primary Mix Designs(1)

Mix No.(2)	Cement kg/m^3	Flyash kg/m^3	Silica kg/m^3	Coarse kg/m^3	Sand kg/m^3
57,58	500	0	0	655	685
63,64	462	0	38	640	685
69,70	425	0	75	635	685
75,76	440	60	0	635	685
81,82	402	60	38	630	685
87,88	365	60	75	625	685
93,94	375	125	0	620	685
99,100	337	125	38	615	685
105,106	300	125	75	610	685

Note: (1) Design Plastic Features
(a) Target Slump 180 mm
(b) Target Air Content 3.0%

(2) Admixtures
(a) Odd Numbered Mixes Grace Daratard 17
Low Range 300 ml/100 kg cementitious
Grace Daracem DX100 HRWRA 1200 ml/100 kg cementitious

or (b) Even Numbered Mixes Masterbuilders 100XR
Low Range 150 ml/100 kg cementitious
Masterbuilders PS847 HRWRA 1200 ml/100 kg

Table 1.C.3

Avon Aggregates

550 kg/m^3 Cementitious

Primary Mix Designs(1)

Mix No.(2)	Cement kg/m^3	Flyash kg/m^3	Silica kg/m^3	Coarse kg/m^3	Sand kg/m^3
111,112	550	0	0	630	670
117,118	510	0	40	625	670
123,124	470	0	80	620	670
129,130	485	65	0	615	670
135,136	445	65	40	615	670
141,142	405	65	80	605	670
147,148	412	138	0	605	670
153,154	377	138	35	595	670
159,160	342	138	70	595	670

Note: (1) Design Plastic Features
(a) Target Slump 180 mm
(b) Target Air Content 3.0%
(2) Admixtures
(a) Odd Numbered Mixes Grace Daratard 17
Low Range 300 ml/100 kg cementitious
Grace Daracem DX100 HRWRA 1200 ml/100 kg cementitious
or (b) Even Numbered Mixes Masterbuilders 100XR
Low Range 150 ml/100 kg cementitious
Masterbuilders PS847 HRWRA 1200 ml/100 kg

Table 2.A.1.a

Standard Weight Aggregates

450 kg/m^3 Cementitious

Plastic Properties of Trials

Grace Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp °C	Unit Mass kg/m^3	Yield m/m
1	144	0.32	180	5.5	19	2398	1.02
7	152	0.33	190	4.8	17	2387	1.02
13	160	0.35	140	2.6	17	2413	1.01
19	145	0.32	155	3.3	19	2444	1.00
25	144	0.32	175	2.4	18	2411	1.00
31	150	0.33	155	3.3	17	2373	1.01
37	150	0.33	155	3.6	19	2382	1.01
43	131	0.29	165	5.0	17	2324	1.02
49	124	0.27	145	2.8	17	2385	1.00

Table 2.A.1.b

Standard Weight Aggregates

450 kg/m^3 Cementitious

Plastic Properties of Trials

Master Builder Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp ^oC	Unit Mass kg/m^3	Yield m/m
2	139	0.31	175	2.7	19	2485	0.99
8	158	0.35	180	4.5	17	2393	1.02
14	155	0.34	115	2.5	17	2410	1.00
20	149	0.33	160	2.9	19	2445	1.00
26	142	0.31	220	5.0	17	2386	1.01
32	138	0.30	200	3.2	17	2403	1.00
38	152	0.34	165	2.9	16	2404	1.00
44	135	0.29	170	3.0	17	2412	0.99
50	132	0.29	190	2.7	18	2405	0.99

Table 2.A.2.a

Standard Weight Aggregates

500 kg/m^3 Cementitious

Plastic Properties of Trials

Grace Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp ^oC	Unit Mass kg/m^3	Yield m/m
55	158	0.32	130	3.2	19	2411	1.01
61	139	0.28	140	3.6	17	2387	1.01
63	149	0.30	140	3.3	18	2404	1.01
73	155	0.31	145	3.0	19	2443	1.00
79	129	0.26	155	4.5	17	2375	1.01
85	150	0.30	140	2.7	17	2410	1.00
91	152	0.30	160	3.0	16	2342	0.99
97	128	0.26	155	5.8	17	2310	1.02
103	134	0.27	120	3.2	17	2397	0.99

Table 2.A.2.b

Standard Weight Aggregates

500 kg/m^3 Cementitious

Plastic Properties of Trials

Master Builder Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp ^oC	Unit Mass kg/m^3	Yield m/m
56	177	0.35	145	2.9	19	2473	1.00
62	128	0.26	140	4.3	17	2420	1.00
68	131	0.26	140	3.0	17	2443	0.99
74	143	0.29	160	2.7	18	2442	0.99
80	129	0.26	170	3.8	17	2410	1.00
86	138	0.28	180	2.8	17	2408	1.00
92	151	0.30	155	2.9	16	2391	1.00
98	120	0.24	200	4.5	17	2374	1.00
104	122	0.24	155	3.0	18	2412	0.98

Table 2.A.3.a

Standard Weight Aggregates

550 kg/m^3 Cementitious

Plastic Properties of Trials

Grace Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp ^oC	Unit Mass kg/m^3	Yield m/m
109	160	0.29	160	2.8	19	2461	1.00
115	149	0.27	125	3.5	17	2412	1.01
121	158	0.29	150	3.5	17	2416	1.01
127	169	0.31	160	2.9	18	2406	1.01
133	132	0.24	140	4.8	17	2379	1.01
139	148	0.27	170	3.0	17	2383	1.01
145	166	0.30	165	3.2	17	2402	1.01
151	151	0.25	140	4.5	17	2342	1.02
157	145	0.26	130	3.5	17	2374	1.00

Table 2.A.3.b

Standard Weight Aggregates

550 kg/m^3 Cementitious

Plastic Properties of Trials

Master Builder Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp ^oC	Unit Mass kg/m^3	Yield m/m
110	161	0.29	160	2.7	19	2472	1.00
116	135	0.25	180	5.3	17	2380	1.01
122	136	0.25	140	3.6	17	2439	1.00
128	165	0.30	155	2.8	19	2436	1.00
134	129	0.24	180	3.2	17	2458	0.98
140	139	0.25	160	3.5	18	2413	1.00
146	169	0.31	175	2.8	17	2384	1.01
152	128	0.23	155	4.0	17	2384	0.99
158	145	0.26	150	3.0	17	2385	1.00

Table 2.B.1.a

Herculite Aggregates

450 kg/m^3 Cementitious

Plastic Properties of Trials

Grace Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp °C	Unit Mass kg/m^3	Yield m/m
5	157	0.35	120	4.5	17	1969	1.01
11	155	0.34	145	3.2	17	2052	0.98
17	152	0.34	100	2.7	17	2013	0.99
23	153	0.34	160	4.0	17	1968	1.00
29	161	0.36	150	2.4	18	1991	1.00
35	147	0.33	135	3.0	17	1978	0.99
41	145	0.32	150	3.7	17	1974	1.00
47	127	0.28	140	2.3	17	1980	0.98
53	152	0.34	125	2.9	17	1991	0.99

Table 2.B.1.b

Herculite Aggregates

450 kg/m^3 Cementitious

Plastic Properties of Trials

Master Builder Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp °C	Unit Mass kg/m^3	Yield m/m
6	160	0.35	145	3.0	17	1992	1.00
12	134	0.30	185	4.8	17	1995	0.99
18	154	0.34	140	2.6	17	2020	0.98
24	151	0.33	155	3.0	17	1964	1.01
30	122	0.27	200	2.5	17	2004	0.97
36	125	0.28	135	2.2	18	1977	0.98
42	152	0.34	140	2.9	17	1988	0.99
48	126	0.28	185	4.2	17	1973	0.99
54	125	0.28	150	3.1	17	1999	0.97

Table 2.B.2.a

Herculite Aggregates

500 kg/m^3 Cementitious

Plastic Properties of Trials

Grace Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp °C	Unit Mass kg/m^3	Yield m/m
59	169	0.34	160	4.0	16	2008	1.01
65	171	0.34	140	2.8	17	1979	1.02
71	164	0.33	110	2.8	18	1970	1.02
77	155	0.31	150	3.5	17	1969	1.01
83	133	0.27	135	5.0	17	1936	1.02
89	154	0.31	120	2.5	18	1941	1.02
95	154	0.31	160	2.5	17	1958	1.01
101	143	0.29	180	4.9	17	1873	1.05
107	150	0.30	140	2.5	17	1914	1.03

Table 2.B.2.b

Herculite Aggregates

500 kg/m^3 Cementitious

Plastic Properties of Trials

Master Builder Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp ^{o}C	Unit Mass kg/m^3	Yield m/m
60	161	0.32	145	2.5	16	2008	1.00
66	136	0.27	200	3.9	17	1943	1.02
72	148	0.30	130	2.5	17	2028	0.99
78	160	0.32	160	3.8	18	1992	0.99
84	135	0.27	165	4.4	17	1965	1.00
90	145	0.29	165	2.0	17	1945	1.02
96	155	0.31	140	2.9	17	1971	1.00
102	148	0.30	140	4.7	17	1891	1.03
108	138	0.28	165	2.6	17	1972	0.99

Table 2.B.3.a

Herculite Aggregates

550 kg/m^3 Cementitious

Plastic Properties of Trials

Grace Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp °C	Unit Mass kg/m^3	Yield m/m
113	170	0.31	165	4.2	17	1972	1.02
119	160	0.29	140	2.6	17	1945	1.03
125	186	0.34	130	2.8	17	1959	1.03
131	167	0.30	185	3.9	17	1950	1.02
137	165	0.30	165	4.7	17	1948	1.03
143	176	0.32	150	2.6	17	1973	1.03
149	164	0.30	175	4.2	17	1996	1.01
155	138	0.25	175	4.8	17	1902	1.03
161	159	0.29	135	2.7	17	1918	1.03

Table 2.B.3.b

Herculite Aggregates

550 kg/m^3 Cementitious

Plastic Properties of Trials

Master Builder Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp ^oC	Unit Mass kg/m^3	Yield m/m
114	168	0.31	175	3.6	17	1973	1.02
120	163	0.30	120	2.8	17	1999	1.01
126	158	0.29	130	2.5	17	1976	1.02
132	170	0.31	185	4.0	17	1953	1.02
138	145	0.26	140	3.6	17	1971	1.02
144	159	0.29	150	2.7	17	1950	1.03
150	168	0.31	180	3.0	17	2010	1.00
156	150	0.27	190	3.0	17	1970	1.01
162	145	0.26	155	2.7	17	1985	1.00

Table 2.C.1.a

Avon Aggregates

450 kg/m^3 Cementitious

Plastic Properties of Trials

Grace Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp ^oC	Unit Mass kg/m^3	Yield m/m
3	128	0.28	140	4.5	17	1924	0.99
9	121	0.27	100	2.1	17	1988	0.97
15	136	0.30	140	2.6	17	1990	0.97
21	122	0.27	165	5.8	17	1840	1.03
27	138	0.31	140	2.9	17	1966	0.98
33	130	0.29	150	2.3	17	1948	0.98
39	135	0.30	180	4.8	17	1880	1.01
45	131	0.29	180	4.9	17	1924	0.98
51	137	0.27	180	2.0	17	2011	0.95

Table 2.C.1.b

Avon Aggregates

450 kg/m^3 Cementitious

Plastic Properties of Trials

Master Builder Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp ^oC	Unit Mass kg/m^3	Yield m/m
4	132	0.29	200	3.6	17	1923	1.00
10	138	0.30	130	2.5	17	1989	0.97
16	132	0.29	150	2.6	17	1995	0.97
22	119	0.27	200	4.1	17	1922	0.99
28	126	0.28	200	3.7	17	1969	0.97
34	133	0.30	170	1.8	17	1988	0.95
40	129	0.29	200	3.5	17	1961	0.97
46	125	0.28	180	2.7	17	1940	0.97
52	120	0.27	180	2.0	17	2011	0.95

Table 2.C.2.a

Avon Aggregates

500 kg/m^3 Cementitious

Plastic Properties of Trials

Grace Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp °C	Unit Mass kg/m^3	Yield m/m
57	147	0.30	140	2.5	17	2002	0.99
63	153	0.31	140	1.6	16	1956	0.99
69	136	0.27	150	2.0	17	1989	0.99
75	142	0.28	200	6.8	17	1878	1.04
81	126	0.25	130	2.5	17	1944	1.00
87	132	0.26	130	2.9	16	1956	0.99
93	128	0.26	200	5.2	19	1882	1.03
99	117	0.21	170	5.6	17	1894	1.00
105	126	0.25	150	2.2	17	1932	0.99

Table 2.C.2.b

Avon Aggregates

500 kg/m^3 Cementitious

Plastic Properties of Trials

Master Builder Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp °C	Unit Mass kg/m^3	Yield m/m
58	148	0.30	200	2.4	17	2007	0.98
64	140	0.28	145	2.1	17	1982	1.00
70	151	0.30	150	2.2	17	2002	0.99
76	125	0.25	200	3.8	17	2010	0.97
82	117	0.22	180	4.4	19	1970	0.98
88	123	0.24	160	2.1	19	1987	0.98
94	123	0.25	200	3.0	17	1967	0.98
100	116	0.23	135	1.7	17	1999	0.97
106	117	0.22	160	2.3	17	1966	0.97

Table 2.C.3.a

Avon Aggregates

550 kg/m^3 Cementitious

Plastic Properties of Trials

Grace Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp °C	Unit Mass kg/m^3	Yield m/m
111	152	0.28	200	4.0	17	2002	1.00
117	152	0.28	140	3.1	17	1918	1.03
123	160	0.29	130	2.5	17	1984	1.00
129	126	0.23	160	2.8	17	1965	1.00
135	127	0.23	140	2.0	19	1913	1.03
141	150	0.27	145	2.0	19	1954	1.01
147	133	0.24	200	3.0	19	1971	0.99
153	127	0.23	160	4.1	17	1908	1.01
159	114	0.21	140	2.5	17	1889	1.02

Table 2.C.3.b

Avon Aggregates

550 kg/m^3 Cementitious

Plastic Properties of Trials

Master Builder Admixtures

Mix No.	Water litres/m	W:Ce Ratio	Slump mm	Air %	Temp ^oC	Unit Mass kg/m^3	Yield m/m
112	146	0.27	190	3.3	17	2002	1.00
118	131	0.24	125	2.7	17	2020	0.98
124	138	0.25	135	2.1	19	2012	0.98
130	132	0.24	200	3.0	17	1991	0.99
136	122	0.22	190	3.2	19	1959	1.00
142	144	0.26	155	1.6	19	1985	1.00
148	124	0.22	200	2.2	17	2019	0.98
154	113	0.21	190	2.7	17	1971	0.98
160	125	0.22	110	1.9	18	1970	1.01

Table 3.A.1.a

Standard Weight Aggregates

450 kg/m^3 Cementitious

Properties of Hardened Concrete

Grace Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
1	55.9	63.1	59.8	2505	4.3	4.1	4.3
7	38.4	57.5	57.9	2425	4.0	4.2	4.9
13	55.5	75.9	74.5	2430	4.0	(4)	4.3
19	55.6	63.9	66.5	2485	3.9	4.5	5.0
25	57.1	69.0	78.6	2455	4.1	4.4	4.0
31	55.3	76.5	84.1	2405	4.0	4.6	4.3
37	49.4	61.7	67.9	2455	4.0	4.3	4.6
43	16.1	63.0	64.8	2400	4.5	4.1	4.2
49	13.1	54.6	70.7	2400	3.9	(4)	4.4

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air
(4) Testing record lost

Table 3.A.1.b

Standard Weight Aggregates

450 kg/m^3 Cementitious

Properties of Hardened Concrete

Master Builder Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
2	55.4	70.0	78.5	2485	4.2	5.0	4.1
8	35.4	57.2	66.2	2450	4.5	4.4	4.4
14	61.7	70.3	72.9	2450	4.4	4.7	4.2
20	56.0	62.3	60.9	2505	4.2	4.2	4.7
26	43.8	69.2	70.3	2400	4.1	4.3	4.6
32	48.1	66.6	68.1	2455	5.0	4.1	4.2
38	47.5	48.3	58.9	2475	3.7	4.3	5.0
44	35.7	70.5	75.7	2410	4.2	4.6	4.6
50	45.9	76.8	78.0	2445	4.4	4.8	5.1

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.A.2.a

Standard Weight Aggregates

500 kg/m^3 Cementitious

Properties of Hardened Concrete

Grace Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
55	62.5	78.4	78.0	2500	4.1	4.4	4.6
61	65.3	81.1	74.9	2470	4.3	4.6	4.9
67	39.2	79.1	74.6	2455	4.5	4.6	4.6
73	53.0	61.0	74.1	2485	3.9	4.3	4.7
79	43.1	71.2	76.0	2425	4.3	4.7	4.8
85	64.3	80.5	80.9	2445	4.9	4.8	4.7
91	53.0	58.5	82.5	2485	4.0	4.5	4.6
97	38.9	72.6	70.5	2360	3.6	4.1	5.0
103	36.1	68.8	68.8	2400	4.5	4.5	4.9

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.A.2.b

Standard Weight Aggregates

500 kg/m^3 Cementitious

Properties of Hardened Concrete

Master Builder Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile[3] 28 day MPa	91 day MPa	Wet[2]
56	50.4	61.9	70.1	2500	4.0	4.2	4.5
62	71.8	88.4	82.9	2515	4.9	5.7	5.1
68	73.9	82.9	94.7	2480	5.0	5.5	5.0
74	52.1	61.0	61.4	2485	3.9	4.2	4.5
80	62.8	82.4	82.2	2460	5.0	4.8	5.1
86	64.9	79.4	68.1	2455	4.4	5.1	4.5
92	47.5	59.2	64.1	2425	3.8	4.1	4.6
98	43.8	71.2	74.2	2425	5.0	4.6	5.0
104	44.3	83.6	73.5	2450	4.6	5.2	4.9

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.A.3.a

Standard Weight Aggregates

550 kg/m^3 Cementitious

Properties of Hardened Concrete

Grace Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile[3] 28 day MPa	91 day MPa	Wet[2]
109	53.3	62.0	68.4	2490	3.9	4.1	4.5
115	67.4	85.7	87.5	2480	4.7	4.7	5.2
121	57.0	80.7	87.8	2490	4.7	5.5	4.7
127	58.1	62.2	67.3	2475	3.9	4.0	4.6
133	42.8	67.4	98.7	2445	4.5	4.7	5.0
139	66.1	72.6	90.4	2440	4.7	4.7	4.6
145	46.4	59.7	76.2	2395	4.4	4.7	4.8
151	26.3	70.8	89.2	2370	4.0	4.2	4.8
157	40.9	56.2	86.7	2405	4.4	4.3	4.5

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.A.3.b

Standard Weight Aggregates

550 kg/m^3 Cementitious

Properties of Hardened Concrete

Master Builder Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
110	49.8	53.0	67.9	2530	4.1	4.2	4.4
116	73.7	85.5	78.6	2510	4.8	4.9	5.3
122	74.7	92.4	86.2	2480	4.5	5.2	5.1
128	58.3	69.0	59.6	2475	4.0	4.3	4.3
134	65.2	84.1	92.6	2450	4.7	5.1	5.1
140	64.1	67.3	92.3	2465	4.5	4.9	4.6
146	45.2	52.0	64.1	2435	4.3	4.3	4.4
152	54.5	65.6	84.4	2435	4.4	4.8	4.8
158	65.4	56.0	77.8	2410	4.7	4.8	4.6

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.B.1.a

Herculite Aggregates

450 kg/m^3 Cementitious

Properties of Hardened Concrete

Grace Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile[3] 28 day MPa	91 day MPa	Wet[2]
5	43.4	52.1	51.3	2025	3.8	4.0	4.3
11	59.2[4]	67.7	60.8	2040	3.8	3.9	4.3
17	49.4	58.4	58.7	2065	4.0	3.8	4.6
23	49.6	56.0	56.9	2025	3.4	3.9	4.1
29	28.5	57.7	64.8	2000	3.8	3.9	4.3
35	27.8	59.3	58.5	1985	3.6	3.6	4.4
41	44.2	57.1	54.6	2045	3.9	4.0	4.1
47	21.6	52.5	54.2	1955	3.7	3.8	4.2
53	20.8	44.5	46.7	1920	3.6	3.8	3.8

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air
(4) 13 day compressive strength

Table 3.B.1.b

Herculite Aggregates

450 kg/m^3 Cementitious

Properties of Hardened Concrete

Master Builder Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
6	41.5	55.4	58.8	2025	3.6	4.0	4.1
12	46.0	60.2	52.0	2055	3.9	4.2	4.4
18	54.2	56.6	61.4	2035	3.7	4.0	4.1
24	44.1	51.6	51.1	2020	4.0	4.1	4.4
30	40.2	52.2	66.7	2010	3.7	3.8	3.9
36	31.9	57.4	59.8	1980	4.0	3.7	4.1
42	43.9	53.9	59.1	2025	3.9	4.0	3.8
48	<5	49.1	59.0	1920	3.6	3.3	4.1
54	25.2	57.6	60.0	1995	4.3	3.8	4.5

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.B.2.a

Herculite Aggregates

500 kg/m^3 Cementitious

Properties of Hardened Concrete

Grace Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
59	44.1	47.4	48.5	1945	3.9	4.0	4.2
65	44.3	50.8	56.7	2000	4.2	3.9	3.8
71	46.1	62.7	63.5	1995	3.9	3.6	3.7
77	51.2	53.8	53.8	2045	3.7	3.6	4.4
83	42.7	55.1	64.7	(4)	(4)	(4)	(4)
89	37.2	57.1	58.9	2000	3.9	3.6	4.3
95	42.8	57.2	56.8	1995	3.6	4.0	3.8
101	22.2	55.4	53.3	1935	3.7	3.9	4.1
107	15.2	43.0	54.7	1920	3.1	3.8	3.7

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air
(4) Testing records lost

Table 3.B.2.b

Herculite Aggregates

500 kg/m^3 Cementitious

Properties of Hardened Concrete

Master Builder Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile[3] 28 day MPa	91 day MPa	Wet[2]
60	50.2	59.2	60.3	2050	3.6	4.4	4.0
66	48.7	58.5	63.5	2010	3.7	4.0	4.5
72	51.1	64.3	65.0	(4)	(4)	(4)	(4)
78	41.1	52.5	52.1	2050	3.6	3.5	4.4
84	33.6	48.7	60.9	2000	3.6	4.5	4.5
90	44.3	49.1	62.5	1965	4.0	3.6	4.2
96	43.4	53.8	58.5	2040	3.6	3.8	3.7
102	11.2	42.8	55.3	1900	3.9	4.0	3.7
108	34.7	59.2	65.3	1990	3.9	3.9	4.3

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air
(4) Testing records lost

Table 3.B.3.a

Herculite Aggregates

550 kg/m^3 Cementitious

Properties of Hardened Concrete

Grace Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
113	44.2	56.3	62.7	2030	4.1	3.7	4.3
119	48.5	66.6	62.2	2050	3.9	3.8	3.8
125	50.9	55.9	55.9	1975	3.6	3.8	4.1
131	48.1	57.1	63.9	1975	3.9	4.0	3.9
137	41.5	63.8	57.9	2000	3.6	3.7	3.9
143	46.8	54.4	56.8	1975	3.5	3.9	3.8
149	44.2	51.6	53.0	2030	3.7	4.0	4.3
155	<5	46.2	51.5	1960	3.5	3.7	4.0
161	26.5	40.2	56.8	1950	3.5	3.7	4.1

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.B.3.b

Herculite Aggregates

550 kg/m^3 Cementitious

Properties of Hardened Concrete

Master Builder Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
114	47.9	53.3	58.1	2014	3.9	3.6	4.4
120	59.2	52.2	62.6	2020	3.9	3.9	4.0
126	56.8	59.1	54.6	2000	4.0	3.3	4.0
132	43.2	48.6	49.0	1995	3.7	3.8	4.2
138	48.5	56.8	59.3	1965	4.0	3.4	4.0
144	43.1	60.6	62.3	1980	3.6	3.6	3.8
150	43.1	52.2	50.4	2025	3.8	3.9	4.4
156	37.1	54.9	65.6	2000	3.7	3.6	3.7
162	37.5	57.6	60.1	2025	3.5	3.9	4.1

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.C.1.a

Avon Aggregates

450 kg/m^3 Cementitious

Properties of Hardened Concrete

Grace Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
3	51.1	60.6	63.7	1975	3.8	4.0	4.3
9	47.9	54.2	71.3	2050	3.9	4.0	4.6
15	47.1	59.3	66.1	2000	3.5	3.8	3.8
21	<5	45.2	58.5	1915	3.1	3.4	3.7
27	5.2	59.0	61.9	1945	3.7	3.8	3.9
33	6.8	48.5	63.0	1945	4.2	3.7	4.0
39	<5	13.3	60.7	1840	1.3	2.7	3.8
45	<5	36.7	66.2	1958	3.6	3.4	4.4
51	24.8	46.9	66.7	1955	3.7	3.5	3.8

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.C.1.b

Avon Aggregates

450 kg/m^3 Cementitious

Properties of Hardened Concrete

Master Builder Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile[3] 28 day MPa	91 day MPa	Wet[2]
4	38.4	45.2	54.4	1965	4.0	4.0	4.5
10	62.8	67.8	67.0	1995	3.9	4.4	3.8
16	56.6	65.6	60.8	2000	4.4	4.0	4.1
22	<5	48.6	51.2	1980	3.4	3.8	3.7
28	34.9	55.3	67.4	2040	4.1	4.0	3.5
34	47.4	47.4	55.4	1985	4.0	4.0	4.5
40	<5	37.9	49.4	1955	3.0	3.8	4.0
46	5.2	56.2	66.2	1995	3.8	4.1	3.8
52	12.7	59.4	72.9	2015	3.7	3.8	4.6

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.C.2.a

Avon Aggregates

500 kg/m^3 Cementitious

Properties of Hardened Concrete

Grace Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
57	45.6	69.5	70.5	2050	4.3	3.8	4.5
63	5.2	55.0	61.0	1950	3.9	3.5	4.3
69	46.2	62.0	71.8	2010	4.1	4.4	3.9
75	<5	36.1	59.4	1880	3.4	3.9	4.0
81	12.5	66.6	65.6	1955	3.6	3.6	4.3
87	40.8	65.4	70.5	1960	3.7	3.4	3.7
93	5	35.8	50.0	1870	3.6	3.5	4.4
99	5	40.5	60.3	1890	2.2	2.8	4.2
105	41.9	54.3	58.5	1940	3.7	4.1	3.7

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.C.2.b

Avon Aggregates

500 kg/m^3 Cementitious

Properties of Hardened Concrete

Master Builder Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
58	56.8	61.0	60.3	2035	4.4	3.8	4.0
64	42.2	67.5	67.8	2005	4.1	3.8	3.8
70	24.8	73.3	78.8	2010	3.4	4.2	3.7
76	36.6	55.4	60.1	1995	3.6	3.6	3.9
82	23.3	63.3	66.4	2005	3.8	3.9	4.4
88	33.4	69.9	71.4	2005	3.9	3.8	3.9
94	5	38.4	46.1	1955	2.9	4.0	3.8
100	42.1	66.7	69.5	2010	3.7	4.0	4.0
106	46.0	55.4	68.3	2000	3.6	4.2	5.0

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.C.3.a

Avon Aggregates

550 kg/m^3 Cementitious

Properties of Hardened Concrete

Grace Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
111	25.0	50.9	56.7	2040	3.7	4.0	4.1
117	53.7	64.9	62.4	1960	4.2	4.0	3.7
123	55.4	71.3	60.2	2025	3.8	3.9	3.8
129	10.5	58.0	58.9	1995	4.0	3.4	4.4
135	48.9	64.3	69.7	1955	4.1	4.1	3.8
141	38.5	66.4	67.7	1985	3.8	3.5	3.6
147	40.2	52.5	64.7	1945	3.2	4.0	3.5
153	35.1	57.9	66.6	1965	3.7	3.7	4.4
159	30.2	68.7	68.8	1915	4.2	3.4	3.6

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air

Table 3.C.3.b

Avon Aggregates

550 kg/m^3 Cementitious

Properties of Hardened Concrete

Master Builder Admixtures

Mix No.	Compressive Strength 7 day MPa	28 day MPa	91 day MPa	Unit Mass kg/m^3	Split Tensile(3) 28 day MPa	91 day MPa	Wet(2)
112	58.7	58.3	58.8	2040	4.1	3.8	3.9
118	50.6	59.6	70.5	2070	4.0	4.4	4.2
124	(4)	75.2	73.7	2040	4.3	4.0	4.1
130	36.7	56.4	64.7	2000	3.9	4.4	4.2
136	67.8	69.7	68.1	2025	3.7	3.6	4.0
142	55.1	68.7	69.4	2010	3.7	3.6	3.8
148	5.0	49.1	49.9	2000	3.1	3.4	4.2
154	31.6	51.2	63.5	2025	3.6	4.3	4.0
160	26.7	64.0	72.3	2000	3.1	3.6	3.8

Note: (1) All tests average of 2 specimens
(2) Specimens cured in lime saturated water bath for full 91 day period
(3) Curing 7 days water, balance of maturity in laboratory air
(4) Testing record lost

Table 4.A.1.a

Standard Weight Aggregates

450 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Grace Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
1	5.5	62.2	70.2	66.5
7	4.8	41.5	62.2	62.6
13	2.6	54.0	74.5	73.2
19	3.3	56.4	64.8	67.4
25	2.4	55.6	67.1	76.5
31	3.3	56.0	77.5	85.2
37	3.6	50.7	63.4	69.7
43	5.0	17.5	68.7	70.6
49	2.8	14.3	59.5	77.1

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0450]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.A.1.b

Standard Weight Aggregates

450 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Master Builders Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
2	2.7	54.7	69.1	77.4
8	4.5	37.8	61.1	70.7
14	2.5	60.3	68.7	71.3
20	2.9	55.7	62.0	60.6
26	5.0	47.7	75.4	76.6
32	3.2	48.5	67.2	68.7
38	2.9	47.3	48.1	58.6
44	3.0	35.7	70.5	75.7
50	2.7	45.3	75.8	69.1

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0450]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.A.2.a

Standard Weight Aggregates

500 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Grace Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
55	3.2	63.1	79.1	78.7
61	3.6	67.2	83.4	77.0
67	3.3	39.8	80.2	75.7
73	3.0	53.0	61.0	74.1
79	4.5	46.2	76.3	70.7
85	2.7	63.4	79.4	79.7
91	3.0	53.0	58.5	82.5
97	5.8	44.1	82.3	89.9
103	3.2	36.4	69.5	79.4

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0475]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.A.2.b

Standard Weight Aggregates

500 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Grace Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
56	2.9	50.2	61.6	69.8
62	4.3	76.2	93.9	88.0
68	3.0	73.9	82.9	94.7
74	2.7	51.4	60.1	60.5
80	3.8	65.2	85.5	85.3
86	2.8	64.3	78.6	67.5
92	2.9	47.3	58.9	63.8
98	4.5	46.9	76.3	79.5
104	3.0	44.3	83.6	83.5

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0475]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.A.3.a

Standard Weight Aggregates

550 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Grace Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
109	2.8	52.8	61.4	67.7
115	3.5	69.1	87.8	89.7
121	3.5	58.4	82.7	90.0
127	2.9	57.8	61.9	67.0
133	4.8	46.5	73.5	107.5
139	3.0	66.1	72.6	90.4
145	3.2	46.9	60.3	77.0
151	4.5	28.3	76.1	95.9
157	3.5	41.9	57.6	88.9

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)(0.05)]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.A.3.b

Standard Weight Aggregates

550 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Master Builders Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
110	2.7	49.1	52.2	66.9
116	5.3	83.3	93.0	96.1
122	3.6	76.9	95.2	98.8
128	2.8	57.7	68.3	69.0
134	3.2	65.9	84.9	93.5
140	3.5	65.7	69.0	94.6
146	2.8	44.7	51.5	63.5
152	4.0	57.2	68.9	88.6
158	3.0	65.4	56.0	77.8

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)(0.05)]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.B.1.a

Herculite Aggregates

450 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Grace Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
5	4.5	46.3	55.6	54.8
11	3.2	59.7	68.3	51.3
17	2.7	48.7	57.6	53.0
23	4.0	51.8	58.5	59.5
29	2.4	27.7	56.1	63.1
35	3.0	27.8	59.3	58.5
41	3.7	45.6	58.9	56.3
47	2.3	20.9	50.8	52.5
53	2.9	20.7	44.3	46.5

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0450]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.B.1.b

Herculite Aggregates

450 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Master Builders Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
6	3.0	41.5	55.4	58.8
12	4.8	49.7	65.1	66.2
18	2.6	53.2	55.6	60.3
24	3.0	44.1	51.6	51.1
30	2.5	39.3	51.0	65.2
36	2.2	30.8	55.3	57.6
42	2.9	43.7	53.7	58.9
48	4.2	<5	51.8	62.1
54	3.1	25.3	57.9	60.3

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0450]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.B.2.a

Herculite Aggregates

500 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Grace Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
59	4.0	46.2	49.7	50.8
65	2.8	43.9	50.3	56.2
71	2.8	50.7	53.3	52.8
77	3.5	52.4	55.1	54.6
83	5.0	46.8	60.3	70.8
89	2.5	36.3	55.7	59.7
95	2.5	41.8	55.8	55.5
101	4.9	24.2	60.4	58.1
107	2.5	14.8	42.0	53.4

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0475]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.B.2.b

Herculite Aggregates

500 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Master Builders Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
60	2.5	49.0	57.8	58.9
66	3.9	50.8	61.0	66.2
72	2.5	49.9	62.8	63.5
78	3.8	42.7	54.5	54.1
84	4.4	35.8	51.9	64.9
90	2.0	42.2	46.8	59.5
96	2.9	43.2	53.5	58.2
102	4.7	12.1	46.3	59.8
108	2.6	34.0	58.1	64.1

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0475]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.B.3.a

Herculite Aggregates

550 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Grace Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
113	4.2	46.9	59.7	66.5
119	2.6	47.5	65.3	61.0
125	2.8	50.4	54.8	55.3
131	3.9	50.3	59.7	66.8
137	4.7	45.0	69.2	62.8
143	2.6	45.9	53.3	55.7
149	4.2	46.9	54.7	56.2
155	4.8	<5	50.4	56.1
161	2.7	26.1	39.6	55.9

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)(0.05)]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.B.3.b

Herculite Aggregates

550 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Master Builders Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
114	3.6	49.3	54.9	59.8
120	2.8	58.6	51.7	62.0
126	2.5	56.2	58.5	64.1
132	4.0	45.4	51.0	51.5
138	3.6	50.0	58.5	61.1
144	2.7	42.5	60.0	61.4
150	3.0	43.1	52.2	58.4
156	3.0	37.1	54.9	65.6
162	2.7	37.0	56.7	59.2

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)(0.05)]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.C.1.a

Avon Aggregates

450 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Grace Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
3	4.5	54.5	64.7	68.0
9	2.1	46.0	52.0	68.4
15	2.6	46.3	58.2	64.9
21	5.8	<5	50.9	65.9
27	2.9	5.2	58.7	61.6
33	2.3	-	47.0	61.0
39	4.8	<5	14.4	65.6
45	4.9	<5	39.8	71.9
51	2.0	23.7	44.8	63.7

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0450]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.C.1.b

Avon Aggregates

450 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Master Builders Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
4	3.6	39.4	46.4	55.9
10	2.5	61.4	66.3	65.5
16	2.6	55.6	66.6	69.7
22	4.1	<5	51.0	53.7
28	3.7	36.0	57.0	69.5
34	1.8	44.8	44.8	52.4
40	3.5	<5	38.8	50.5
46	2.7	5.1	55.4	65.3
52	2.0	12.1	56.7	69.6

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0450]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.C.2.a

Avon Aggregates

500 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Grace Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
57	2.5	44.6	67.9	68.9
63	1.6	<5	51.6	57.2
69	2.0	44.0	59.1	68.4
75	6.8	<5	41.2	67.9
81	2.5	12.2	65.0	64.0
87	2.9	40.6	65.1	70.2
93	5.2	5.5	39.5	55.2
99	5.6	5.6	45.5	67.7
105	2.2	40.3	52.2	56.3

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0475]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.C.2.b

Avon Aggregates

500 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Master Builders Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
58	2.4	55.2	59.3	58.6
64	2.1	40.4	64.6	64.9
70	2.2	25.7	76.1	81.8
76	3.8	-	57.5	62.4
82	4.4	24.8	67.5	60.2
88	2.1	32.0	66.9	68.3
94	3.0	5	38.4	46.1
100	1.7	39.5	62.5	65.2
106	2.3	44.5	53.6	63.0

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)0.0475]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.C.3.a

Avon Aggregates

550 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Grace Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
111	4.0	26.3	53.4	59.5
117	3.1	54.0	69.0	62.7
123	2.5	54.0	69.5	58.7
129	2.8	10.4	57.4	58.3
135	2.0	46.6	61.2	66.9
141	2.0	36.7	63.2	68.8
147	3.0	<5	52.5	64.7
153	4.1	-	55.4	68.3
159	2.5	29.4	67.0	68.3

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)(0.05)]$

where

f_{corr} = Adjusted Compressive Strength in MPa

f_c = Test Strength

a = Measured Air Content in percent

Table 4.C.3.b

Avon Aggregates

550 kg/m^3 Cementitious

Air Entrainment Adjusted Compressive Strength Properties

Master Builders Admixtures

Mix No.	Air %	7 day MPa	28 day MPa	91 day MPa
112	3.3	59.5	59.2	59.7
118	2.7	49.8	58.7	69.4
124	2.1	-	71.8	77.3
130	3.0	36.7	56.4	64.7
136	3.2	68.5	70.4	67.7
142	1.6	51.5	64.2	57.4
148	2.2	<5	47.1	47.9
154	2.7	31.1	50.4	62.5
160	1.9	25.2	60.2	68.0

Note: Air Adjustment Calculated from

$f_{corr} = f_c[1-(3-a)(0.05)]$

where

f_{corr} = Adjusted Compressive Strength in MPa

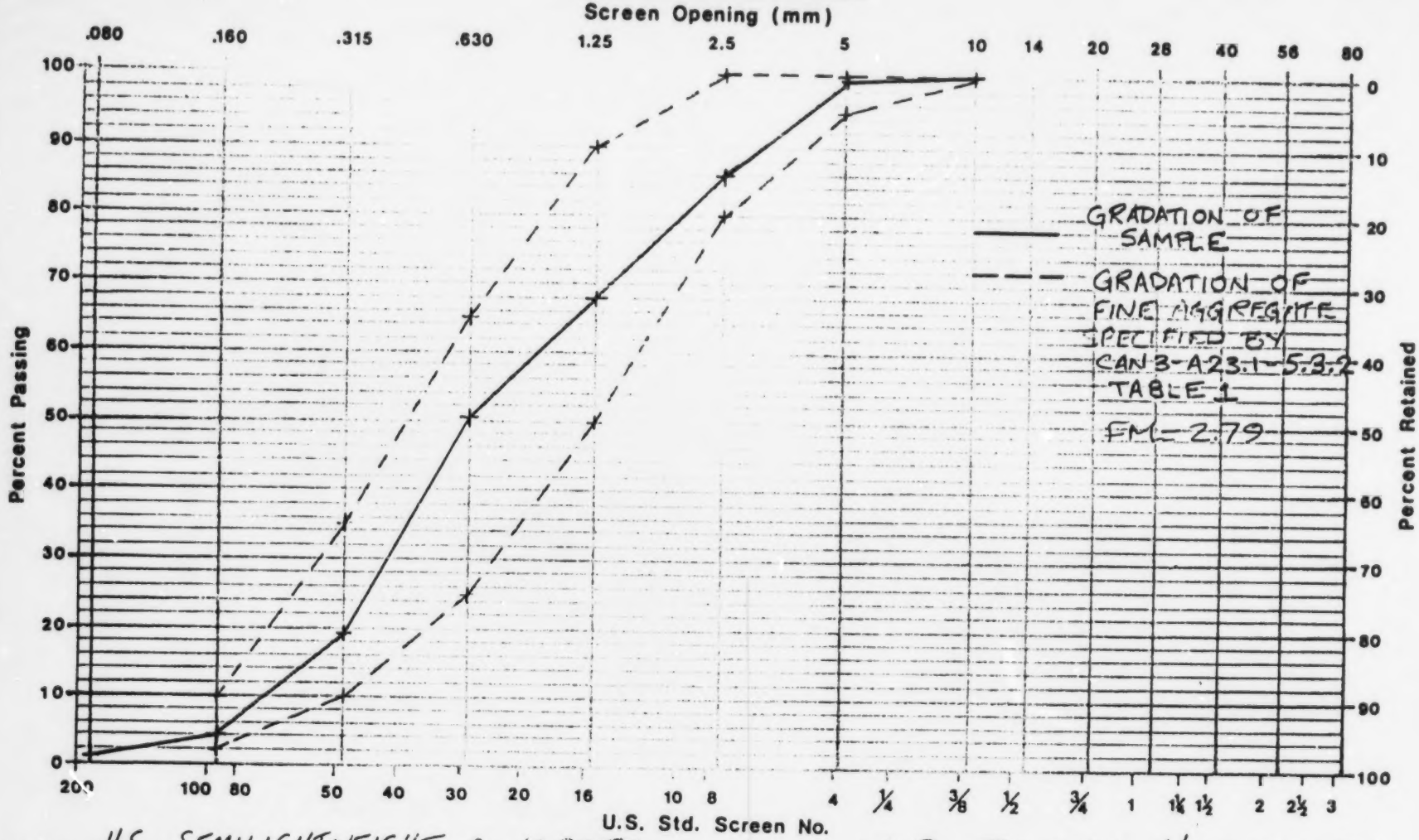
f_c = Test Strength

a = Measured Air Content in percent

APPENDIX 2

MATERIALS

AGGREGATE GRADATION CHART



Project: H.S. SEMILIGHTWEIGHT CONCRETE

Date Sampled: 84-04-03 (KF)

File No.: 83-770

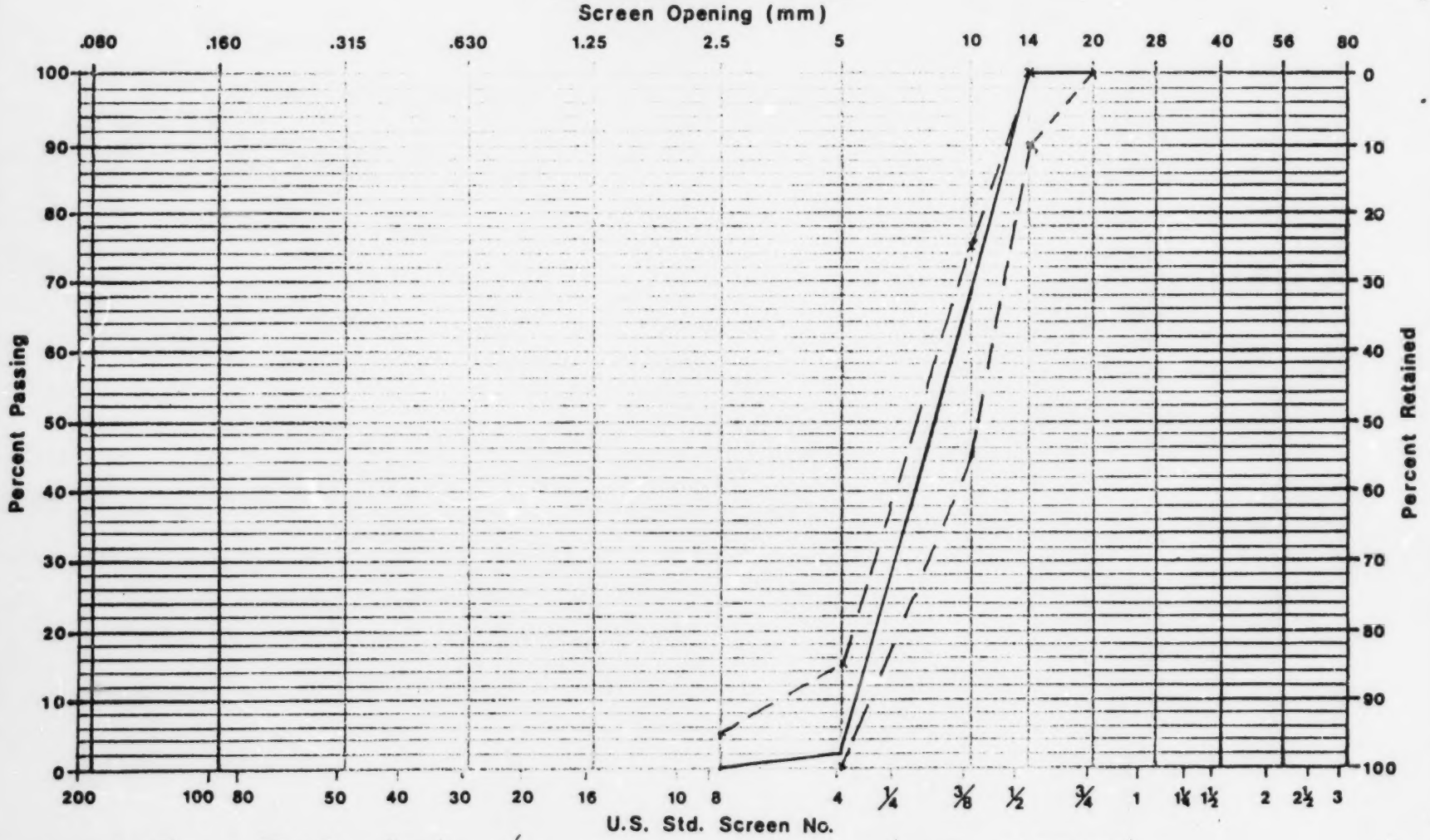
Specification: CAN3-A23.1 - 5.3.2, TABLE 1

Material: SAND, FRIDAY HARBOUR

Sample No.: AB, STANDARD MASS

B.H. LEVELTON & ASSOCIATES LIMITED

AGGREGATE GRADATION CHART



Project: La Tarte Friday Harbour samples

Date Sampled: 83-12-[illegible]

File No.: 83-[illegible]C

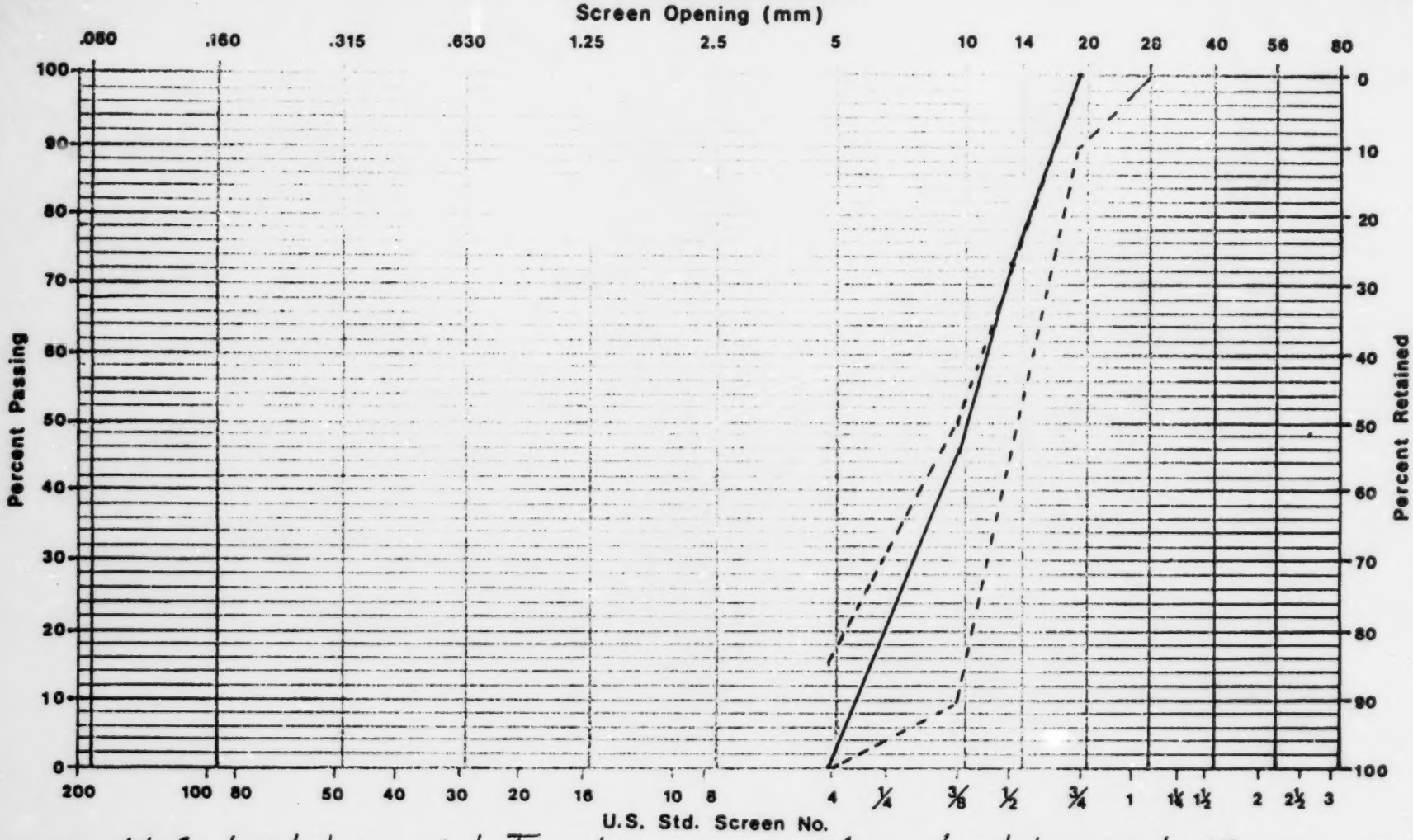
Specification: CSA A23.1

Material: 14mm MATERIAL

Sample No.: AA, STANDARD MASS

B.H. LEVELTON & ASSOCIATES LIMITED

AGGREGATE GRADATION CHART



Project: H.S. Lightweight Trials

Material: Avon Lightweight 19 x 5 mm

Date Sampled: May 1984

Sample No.:

File No.: 83-770

Specification: C320

B.H. LEVELTON & ASSOCIATES LIMITED

APPENDIX 3

DIRECTIONS FROM PHASE I

DEVELOPMENT OF ULTRA-HIGH STRENGTH SEMILIGHTWEIGHT CONCRETE

PHASE I

BACKGROUND DATA ASSEMBLY

Prepared for

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by

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Contract No. : 1SQ83-00206
Requisition No.: 23440-3-9201
Financial Code : 214-131-000000-425252-0421
Levelton File : 83-770C

March 26, 1984

VIII. DIRECTION FOR PHASE II

The results of this Phase I review of technology dictate the following approach to Phase II.

A. Materials Selection

Cement shall be Type 20. This selection is a compromise of optimum corrosion protection versus higher heat of hydration and possible better chemical resistance.

Fly ash should be a Type C (or a Type F with uniformly low carbon) and a minimum pozzolan reactivity with cement of 90%.

Air entraining agent will be a neutralized vinsol resin. Superplasticizer will be the new "extended window" type and a conventional water reducing agent with high water reduction will also be required. This conventional water reducer will be of the non-chloride ion type.

Sand will be of the type considered ideal for precast concrete. The fineness modulus shall be in the 2.8 to 3.0 range.

Lightweight aggregate will be the optimum strength performer from the three remaining Canadian sources.

Silica fume shall be Canadian production as closely approaching Nordic suggested chemical limits as possible.

B. Mix Proportioning

Flowing concrete of 14 mm maximum size aggregate is required.

The optimum pozzolanic content will be in the 20 to 30% of cement range with silica fume being up to one-third of the total.

Cement factors must be less than 600 kg/m^3 and water : cementitious ratios in the 0.25 to 0.30 range in order to minimize heat of hydration and shrinkage.

A realistic unit mass of the air dry semilightweight concrete is 1900 $\pm$ 50 kg/m^3 for the required 70 MPa strength at 90 days.

The coarse aggregate content must be as high as practical to minimize water demand, and maximize volume stability and reduce the unit mass.

Air entrainment must be the minimum level necessary to produce air voids parameters for durable superplasticzed low water : cement ratio concrete. Generally, this appears to include a spacing factor of about 0.23 mm maximum, although this is an over simplification, and the matter of bubble size distribution will have to be addressed.

C. Design Aspects

The primary concrete property that controls structural design is shear strength, both in terms of diagonal tension and punching shear. The latter, measured by methods as yet undefined, should reach 10 MPa.

A compromise is required between the ductility of a low modulus of elasticity concrete that will produce maximum energy absorption and a more brittle higher strength and higher modulus concrete, optimum for design.

The concept of reducing concrete cover on reinforcement by improving concrete permeability appears to be a secondary design consideration.

The marked strength increase with sub-zero temperature bears further future consideration.

D. Testing Aspects

The test procedures for Phase II - compressive and split tensile strength, unit mass - can be accomplished with standard methods.

For Phase III consideration will have to be given to evaluations more closely related to actual offshore structure performance. This includes testing for:

- corrosion protection;
- ice abrasion;
- porosity of paste;
- punching shear;
- relative energy absorption capability.

Some preliminary work on these test methods may be incorporated into the latter stages of Phase II.